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

Deliverable D5.8

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

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EXECUTIVE SUMMARY

The objective of Task 5.9 was to carry out the testing of the Deployment Design tools in order to verify that it meets all the previously defined requirements (detailed in WP5). This report documents the outcome of T5.9 "Verification of the Deployment 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 the 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 available tools 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.

Overall, according to the quantitative results, the end-users involved in evaluating the Deployment Design tools are satisfied with usability, user-friendliness, performance, and value, with generally high scores for all the modules (in the range of 3-5). There are some exceptions to this, for some categories and some modules highlighted in this report as an improvement area for the next version. The qualitative assessment ensured written feedback was gathered, analysed and turned into guidance for improving the next release of the tools. This guidance identified high priority improvements for the tools: 10 for Site Characterisation (SC); 11 for Machine Characterisation (MC); 7 for Energy Capture (EC); 11 for Energy Transformation (ET); 12 for Energy Delivery (ED); 19 for Station Keeping (SK); and 20 for Logistics and Marine Operations (LMO). These will be implemented in the final release of the DTOceanPlus suite of tools.

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ABBREVIATIONS AND ACRONYMS

AD	Assessment Design
AEP	Annual Energy Production
BL	Business Logic
B2B	Back-to-back
CP	Collection Point
CPX	Complexity
CWR	Capture Width Ratio
DD	Deployment Design
DO	Design Objective
DOE	Department of Energy
DoF	Degrees of freedom
EA	Evaluation Area
ED	Energy Delivery
EJPD	Empirical Joint Probability Distribution
ESA	Environmental and Social Acceptance
ET	Energy Transformation
FLS	Fatigue Limit State
FMEA	Failure Mode and Effects Analysis
GUI	Graphical User Interface
HSE	Health Safety and Environment
KPI	Key Performance Indicator
LCOE	Levelised Cost of Energy
LMO	Logistics and Marine Operations
MC	Machine Characterisation
MRE	Marine Renewable Energy
OE	Ocean Energy
OEC	Ocean Energy Converters
OLP	Onshore Landing Point
O&M	Operation and Maintenance
PTO	Power Take Off
RAMS	Reliability Availability Maintainability Survivability
RM	Reference Model
RMP	Reference Model Project
ROV	Remotely Operated Vehicle
SCIG	Squirrel Cage Induction generator
SEF	Software Evaluation Form
SG	Stage Gate
SI	Structured Innovation
SK	Station Keeping
SLC	System Lifetime Costs
SR	Software Routes
ULS	Ultimate Limit State
US	User Stories
VC	Verification Case
VS	Verification Scenario
WEC	Wave Energy Converter
WP	Work Package

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 tool's business logic (e.g., new concept/improvement cycle, …).
Verification Scenarios	A set of independent input/output data to be provided to the end-user for 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 Deployment Design (DD) tools beta version verification. 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 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 DD tools, two *Verification Scenarios* (VSs) were created by using Reference Models (RM) 1 and 3 from Sandia [1]. For some modules (SC, MC, EC and SK) these scenarios were strictly followed. For ET module it was considered a single tidal device (following RM1, for *Verification Case* 1 (VC1) and a tidal array of 10 devices using Sandia's RM1 (for VC2), plus a single wave device (following RM3, for VC3) and a wave array of 10 devices using Sandia's RM3 (for VC4). In the case of ED module, data collected for RM1 and RM3 have been used where possible and also LMO module utilised both data coming from Sandia's reports and synthetic ones to set up the verification scenarios.

After receiving demonstrations and interactive training on how to use the tool, the technical verifiers as well as the industrial verifiers were given access to an online version of the beta version of DD 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 DD 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: DEPLOYMENT DESIGN TOOLS DEVELOPERS, TECHNICAL AND INDUSTRIAL VERIFIERS

Module	Developer	Technical verifier	Industrial verifiers
SC	FEM	AAU	BV, EDP, EGP, IDOM, NOVA, SABELLA
MC	AAU	FEM	BV, EDP, EGP, NOVA, SABELLA
EC	AAU	WavEC	BV, EDP, EGP, IDOM, NOVA, SABELLA
ET	Tecnalia	UEDIN	BV, EDP, EGP, IDOM, SABELLA
ED	UEDIN	WavEC	EDP, EGP, IDOM, SABELLA
SK	FEM	Tecnalia	BV, EDP, EGP, IDOM, NOVA, SABELLA
LMO	WavEC	AAU	BV, EGP, IDOM, SABELLA, WES

The remainder of this section provides short summaries of the DTOceanPlus project and of the DD tools. For further information and background on the project, the reader is directed towards previous deliverables, e.g. [2, 3, 4].

Section 2 outlines the methodology adopted for the verification activities, to later review the Verification Cases (VCs). 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 DD 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 DD 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 Deployment Design tools belong to the suite of tools that the 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.

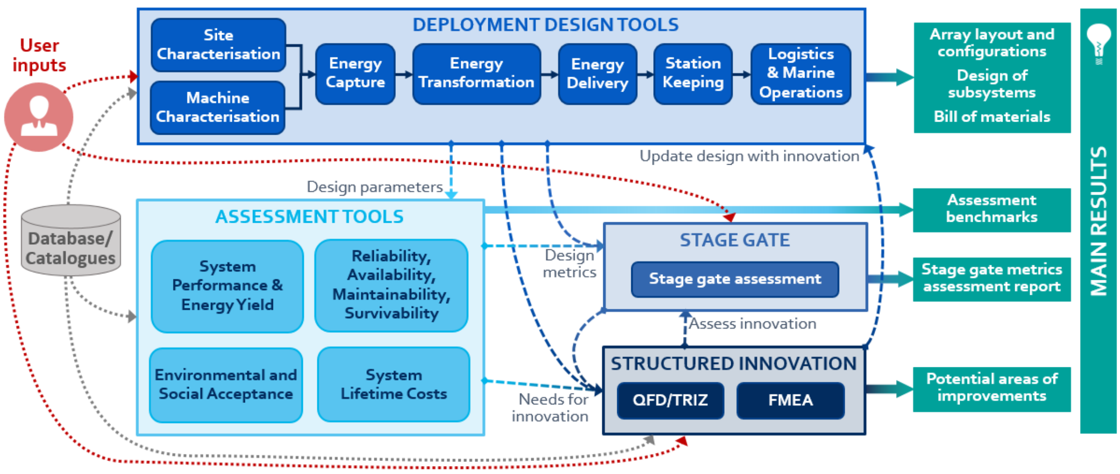


FIGURE 1.1: DTOCEANPLUS MODULES, MAIN LINKAGES AND OUTPUTS

1.3 DEPLOYMENT DESIGN TOOLS

The **Deployment Design tools** will provide optimised solutions and layouts for the deployment of ocean energy technologies and define all the technical design specifications to run the Deployment Design tools for the evaluation of metrics. [5]

This objective is pursued by delivering key calculations and objective information on optimal array development.

The main functionalities of the tools are combined in seven modules:

- **Site Characterisation (SC)** gathers metocean, geotechnical and environmental conditions. This module processes all the site information and elaborates the environmental constraints.
- **Machine Characterisation (MC)** post-processes the technical data inherent to the prime mover in order to be directly usable by the different tools.
- **Energy Capture (EC)** at an array level, assesses and defines optimal solutions for wave and tidal energy converters. The captured power estimated by the Energy Capture module is used as input for the Energy Transformation and Energy Delivery modules.
- **Energy Transformation (ET)** focuses on different PTO systems for tidal and wave energy converters, considering their performance and costs and their impact on reliability, logistics, and environmental issues.
- **Energy Delivery (ED)** deals with electrical and grid issues. In particular, the module objective is to maximise the quality of the electrical power delivered to the onshore distribution network.
- **Station Keeping (SK)** supports the design of the mooring and foundation subsystems, defining a local optimal design solution based on the cost of all components.
- **Logistics and Marine Operation (LMO)** deals with installation, operation, maintenance, and decommissioning, with the aim of minimising the logistic cost in all lifecycle stages, considering different combinations of ports, vessels and support equipment for a given project.

Each of these modules is able to carry out design and assessment at three different levels of complexity (1: low, 2: medium and 3: high).

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 DD 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 DD 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 control data and project data (from catalogues and default data) have been defined and collected (see Section 3).
- **Organisation of training sessions**: training sessions on using 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 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 Cases scenarios have been adapted in accordance with available data produced by the Reference Model Project (RMP) sponsored by the US Department of Energy (DoE) Wind and Water Power Technologies Program. This project aims to produce on-proprietary Reference Models (RM) of technology designs as study objects for open-source research and development programs [6].

The RMs used as part of DTOceanPlus' verification activities are RM1 and RM3; 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.

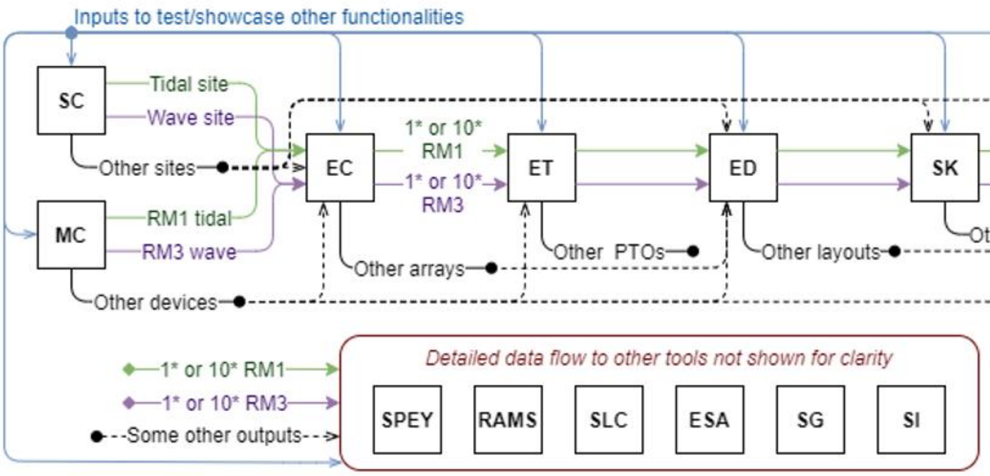


FIGURE 2.1: FLOW OF REFERENCE CASES/DATE BETWEEN THE TOOLS

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.

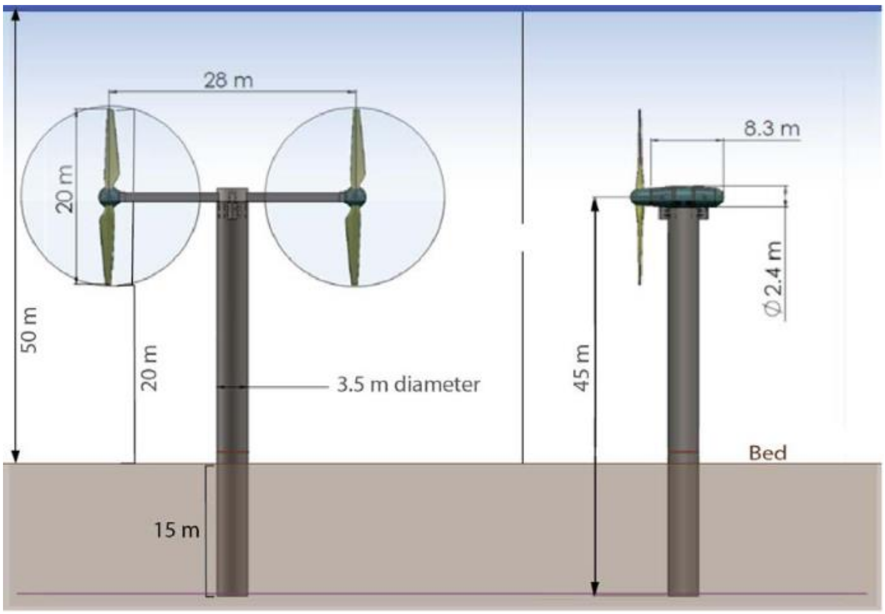


FIGURE 2.2: RM1 DEVICE PROFILE AND PLAN VIEWS DIMENSIONS

The main source of data for this validation scenario is the publication [7]. 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

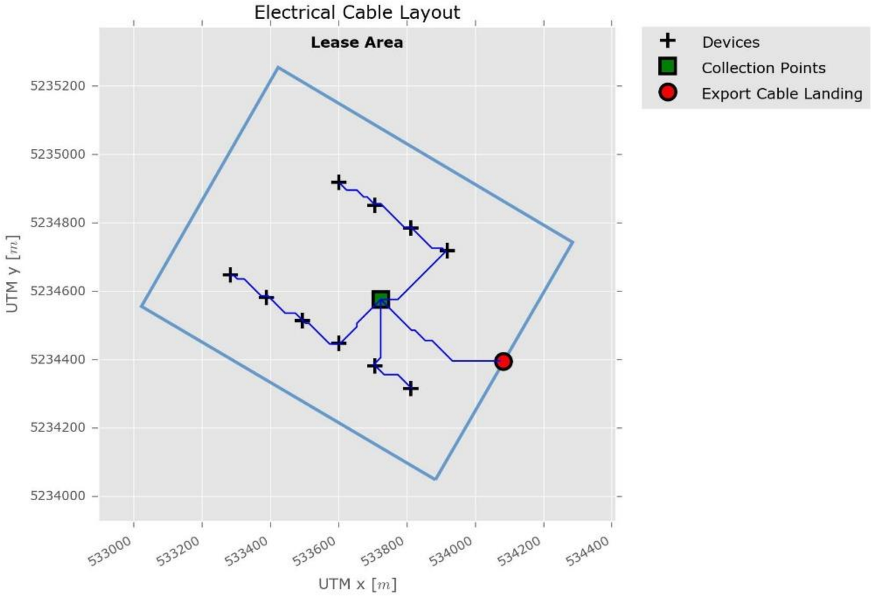


FIGURE 2.3: CABLE AND TURBINE LAYOUT FOR THE VALIDATION SCENARIO 1

The tidal energy resource for RM1 was developed from site information on the Tacoma Narrows tidal site in Puget Sound. For this study, 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.

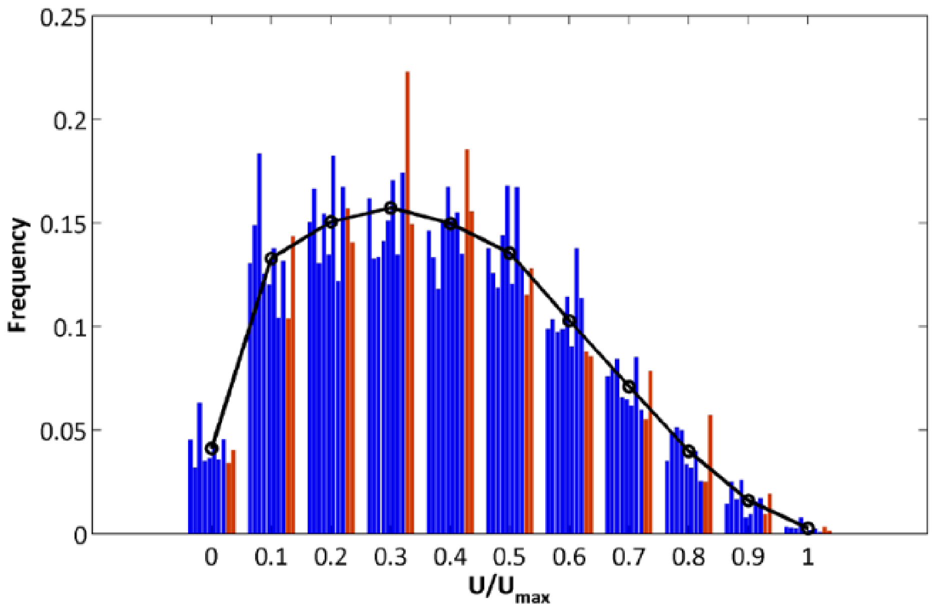


FIGURE 2.4: NON-DIMENSIONAL MID-DEPTH CURRENT SPEED FREQUENCY HISTOGRAMS FOR PUGET SOUND [1]

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 [1].

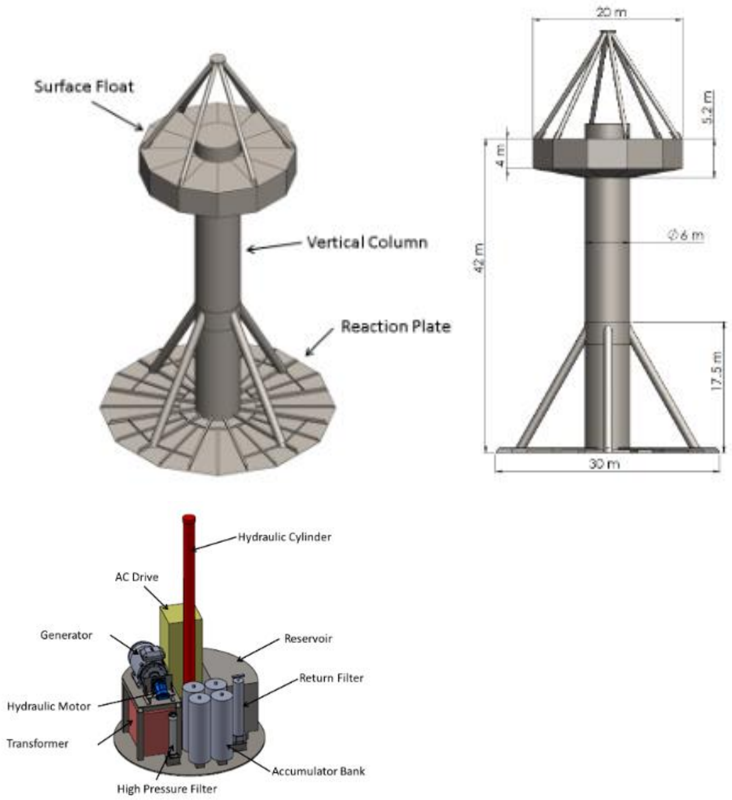


FIGURE 2.5: RM3 DEVICE DESIGN AND DIMENSIONS

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.

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

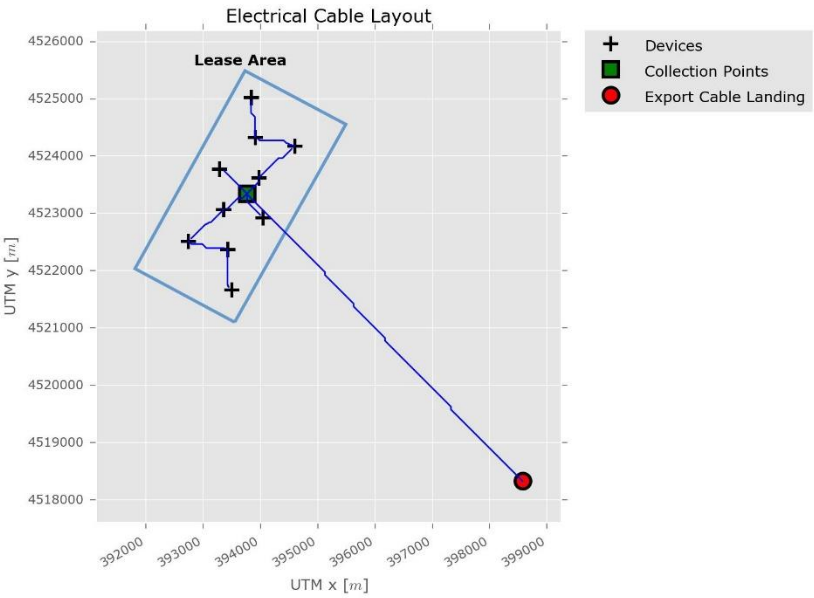


FIGURE 2.6: CABLE AND TURBINES LAYOUT FOR THE VALIDATION SCENARIO 2

The reference wave energy resource for RM3 was developed from site information collected near Eureka in Humboldt County, California [1]. Again, for convenience and this study's purposes, 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
Hs	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%
	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

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 each module's features was given. The conference calls facilitated technical discussions between the developers and the technical verifiers.

A set of dedicated deliverables [8] [9] [10] [11] [12] [13] describing all the potential uses of all Deployment Design tools 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 Deployment Design tools documentation and a list with the VCs.

2.4 EVALUATION CRITERIA

Potential users and other stakeholders (different from the technical and industrial partners) were consulted to identify and clarify their need, requirements and expectations of the Deployment Design tools [2].

The outcome of this user group analysis 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 Deployment Design tools [5] delineated the Evaluation Criteria used throughout the Verification activities. These criteria include a numeric (see Table 2.1) and qualitative assessment for each tool's 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 tool.

The individual Evaluation Criteria included in the Software Evaluation Form are shown in the evaluation results 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 criteria.

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

The Software Evaluation Forms and respective anonymous feedback are included as Annex II and III of this report.

3. VERIFICATION CASES

3.1 SITE CHARACTERISATION (SC)

3.1.1 User flow and experience

The main purpose of the Site Characterisation module is to extract the physical characteristics of a designated site. This module will then provide information to most of the other modules about:

1. The bathymetry;
2. The type of sediment and its associate physical characteristics;
3. The probability of the presence of endangered species;
4. Timeseries and statistics of waves, tidal currents, wind speed and water level fluctuations.

The extracted data is based on input databases provided by default or imported by the user.

In standalone mode, the user first sets up a study, providing a name. They then have to specify input data which are simply energy levels at complexity level 1 and 2, and databases files at complexity level 3.

In integrated mode, using the module does not change as it is upstream from all the other modules.

The main outputs are databases, extraction features and computed statistics based on these extractions.

3.1.2 User Stories

There are two main user stories for the SC 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 estimation of the meteocean conditions of the site by only knowing basic information.*
2. **Full design mode:**
   a. As a *project developer*, I would like to estimate metocean conditions on my study site using my own databases.

3.1.3 Definition of the Verification Cases

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

- **Extraction of 1D metocean parameters** from DTOcean+ database (Complexity level 1),

- **Extraction of 2D metocean parameters** from DTOcean+ database (Complexity level 2),
- **Extraction of 1D or 2D metocean parameters** from user inputs (Complexity level 3),
- **Statistics computation** on the extracted parameters.

Eight Verification Cases (VC) have been defined in order to check these four functionalities, for Wave and Tidal (see Table 3.1). The eight VCs can be grouped into two independent **Verification Scenarios**:

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

TABLE 3.1: FEATURES AND TOTAL NUMBER OF VERIFICATION CASES FOR SC

Feature	Levels of complexity	Dimensions of timeseries (1D/2D)	Other option 1	Other option 2	Total cases	Business logic
Extract DTOcean+ 1D-data and compute statistics	1	1	X	X	1	99%
Extract DTOcean+ 2D-data and compute statistics	2	1	X	X	1	90%
Extract user data (1D or 2D) and compute statistics	3	2	X	X	2	75%

3.1.3.1. Case RM1-SC1

The verification test case RM1-SC-1 is based on the Scenario RM1, with the following user story:

"The user is working within the project described in Scenario RM1. The only information the user has is that the device RM1 is to be deployed in a site with a water depth of around 50m and a high level of tidal current energy. He would like to know the main characteristics of a potential site in terms of tidal currents."

This verification test case focuses on the following functionalities of the SC module:

- Extraction of 1D metocean parameters from DTOcean+ database (Complexity level 1)
- Statistics computation on the extracted parameters.

3.1.3.2. Case RM1-SC2

The verification test case RM1-SC-2 is based on the Scenario RM1, with the following user story:

"The user is working within the project described in Scenario RM1.The only information the user has is that the device RM1 is to be deployed in a site with a water depth of around 50m and a high level of tidal current energy. They would like to know the main characteristics of a potential site in terms of tidal currents and wants 2D results for future farm of devices optimisation."

This verification test case focuses on the following functionalities of the SC module:

- Extraction of 2D metocean parameters from DTOcean+ database (Complexity level 2)
- Statistics computation on the extracted parameters

3.1.3.3. Case RM1-SC3

The verification test case RM1-SC-3 is based on the Scenario RM1, with the following user story:

"The user is working within the project described by Scenario RM1. The user knows that the device RM1 is to be deployed in a site with a water depth of around 50m and has metocean timeseries of this site. They would like to know the main characteristics of a potential site in terms of tidal currents statistics."

This verification test case focuses on the following functionalities of the SC module:

- Extraction of 1D metocean parameters from user inputs (Complexity level 3)
- Statistics computation on the extracted parameters

3.1.3.4. RM1-SC4

The verification test case RM1-SC-4 is based on Scenario E2RM1 (Equivalent European scenario to RM1, within 2D metocean data), with the following user story:

"The user is working within the project described by Scenario E2RM1. The user knows that the device RM1 is to be deployed in a site with a water depth of around 50m and has a 2D metocean timeseries of this site. They would like to know the main characteristics of a potential site in terms of tidal currents statistics."

This verification test case focuses on the following functionalities of the SC module:

- Extraction of 2D metocean parameters from user inputs (Complexity level 3)
- Statistics computation on the extracted parameters

3.1.3.5. RM3-SC1

The verification test case RM3-SC-1 is based on the Scenario RM3, with the following user story:

"The user is working within the project described by Scenario RM3. The user doesn't know anything except that the device RM3 is to be deployed in a site with a water depth of around 90m and a high level of wave energy. They would like to know the main characteristics of a potential site in terms of waves."

This verification test case focuses on the following functionalities of the SC module:

- Extraction of 1D metocean parameters from DTOcean+ database (Complexity level 1)
- Statistics computation on the extracted parameters

3.1.3.6. RM3-SC2

The verification test case RM3-SC-2 is based on the Scenario RM3, with the following user story:

"The user is working within the project described by Scenario RM3. The user doesn't know anything except that the device RM3 is to be deployed in a site with a water depth of around 90m and a high level of wave energy. They would like to know the main characteristics of a potential site in terms of waves, and he wants 2D results for future farm of devices optimisation."

This verification test case focuses on the following functionalities of the SC module:

- Extraction of 2D metocean parameters from DTOcean+ database (Complexity level 2)
- Statistics computation on the extracted parameters

3.1.3.7. RM3-SC3

The verification test case RM3-SC-3 is based on the Scenario RM3, with the following user story:

"The user is working within the project described by Scenario RM3. The user knows that the device RM3 is to be deployed in a site with a water depth of around 90m and has metocean timeseries of this site. They would like to know the main characteristics of a potential site in terms of waves statistics."

This verification test case focuses on the following functionalities of the SC module:

- Extraction of 1D metocean parameters from user inputs (Complexity level 3)
- Statistics computation on the extracted parameters

3.1.3.8. RM3-SC4

The verification test case RM3-SC-4 is based on the Scenario E2RM3 (Equivalent European scenario to RM3, within 2D metocean data), with the following user story:

"The user is working within the project described by Scenario E2RM3. The user knows that the device RM3 is to be deployed in a site with a water depth of around 90m, and he has a 2D metocean timeseries of this site. They would like to know the main characteristics of a potential site in terms of waves statistics."

This verification test case focuses on the following functionalities of the SC module:

- Extraction of 2D metocean parameters from user inputs (Complexity level 3)
- Statistics computation on the extracted parameters

3.1.4 Collection of data required

3.1.4.1. Case RM1-SC1/2 and RM3-SC1/2

The data necessary to run the verification cases are the following:

TABLE 3.2: ENVIRONMENTAL DATA

Inputs description	Value	Units
Wave level of energy	Low / Medium / High	None
Current level of energy	Low / Medium / High	None
Water Depth	RM1: 50 RM3: 90	m

3.1.4.2. Case RM1-SC3/4 and RM3-SC3/4

TABLE 3.3: DATABASES*

Inputs description	Format
Lease Area	Shapefile
Corridor	Shapefile
Seabed Type	Netcdf file
Roughness Length	Netcdf file
Species	Netcdf file
Timeseries	Netcdf file / Excel File
Bathymetry	Constant value / Netcdf file

*Note that all required databases are already available in the SC module and do not need to be downloaded or created. The user only needs to select the correct one among the proposed list.

3.2 MACHINE CHARACTERISATION (MC)

3.2.1 User flow and experience

The Machine Characterisation module and the SC module are particular instances of the design modules, since they can be considered dynamic catalogues. The main roles of the MC module are:

- To prepare the machine data to be used in the rest of the design flow modules. On top of the general data collection role, the MC module can also estimate the hydrodynamic coefficient for a single wave energy converter.
- To prepare the machine data to be used in the rest of the design flow.
- To estimate the hydrodynamic coefficients for a single wave energy converter

The machine data collected in the MC module is pertinent to multiple modules, and it is further divided into three categories:

- General: includes mass, materials, rated power, etc…
- Dimensions: includes overall machine shape, areas and volumes.
- Model: includes machine power performance coefficients.

In standalone mode, the user first sets up a study before entering inputs for the general dimensions and model fields.

Only in wave energy converter cases at complexity 3, the user must perform the evaluation of the hydrodynamic coefficients to finalise the project. Set aside this case, the main outputs of the module are the input themselves.

3.2.2 User Stories

There are six user stories for the Machine Characterisation module due to the possible combination of machine types and project complexity levels. Overall, the user stories can be simplified to a single one, which can be expressed as follows:

1. As a *project* or *device developer*, I would like to collect the information about the machine that can be used in the design process in the DTOceanPlus toolset.

3.2.3 Definition of the Verification Cases

The verification of the MC module features is carried out using six different cases. The definition of the case is summarised in Table 3.4.

TABLE 3.4: MC VERIFICATION CASES

Feature	VC1	VC2	VC3	VC4	VC5	VC6
Technology	Tidal	Tidal	Tidal	Wave	Wave	Wave
Complexity level	1	2	3	1	2	3
Machine Name	RM1	RM1	RM1	RM3	RM3	RM3

3.2.4 Collection of data required

3.2.4.1 Tidal Case

The Machine Characterisation module has three levels of complexity; each complexity level's data requirements are given in the following tables.

TABLE 3.5: RM1 GENERAL INPUTS

Inputs description	Variable Name	Complexity	Value	Units
Connector Type	connector_type	all	"wet"	-
Floating Machine	floating	all	false	bool
Rated Capacity	rated_capacity	all	1100	kW
Constant Power Factor	constant_power_factor	all	0.0	-
Machine Unit Cost	machine_cost	all	1.960.000	EUR
Material Name	materials.material_name	all	"undefined"	-
Material Quantity	materials.material_quantity	all	219370	kg
Max Installation Depth	max_installation_water_depth	all	-45	m
Min Installation Depth	min_installation_water_depth	all	-67.5	m
Min Interdistance X direction (rotation axis)	min_interdistance_x	all	50.0	m
Min Interdistance Y direction (perperndicular to rotation axis)	min_interdistance_y	all	50.0	m
Target Fundation Type	preferred_fundation_type	all	"pile"	-
Rated Voltage	rated_voltage	all	11.000	V

TABLE 3.6: RM1 DIMENSION INPUTS

Inputs description	Variable Name	Complexity	Value	Units
Beam Wet Area	beam_wet_area	3	330.0	m²
Rotor Diameter	characteristic_dimension	all	20.0	m
Draft	"draft": 0.0,	all	0.0	m
Dry frontal area	dry_frontal_area	3	0	m²
Dry profile	dry_profile	all	-	-
Footprint Radius	footprint_radius	all	20	m
Total Height	height	all	30	m
Hub heigth	hub_heigth	3	30.0	m
Total Length	length	all	3.5	m
Total Mass	mass	all	219370.0	kg
Submerged volume	submerged_volume	all	433.0	m³
Wet Area	wet_area	all	-	m²
Wet Frontal Area	wet_frontal_area	3	165.0	m²
Wet Profile	wet_profile	all	-	-
Total Width	width	all	3.5	m

TABLE 3.7: RM1 MODEL COMPLEXITY 1

Inputs description	Variable Name	Value	Units
Power Coefficient	cp	0.37	-
Number of Rotor	number_rotor	2	-

TABLE 3.8: RM1 MODEL COMPLEXITY 2

Inputs description	Variable Name	Value	Units
Power Coefficient	cp	0.37	-
Trust Coefficient	ct	0.43	-
Cut-in Velocity	cut_in_velocity	0.5	m/s
Cut-out Velocity	cut_out_velocity	3	m/s
Number of Rotor	number_rotor	2	-
Rotor Horizontal Interdistance (direction perpendicular to the rotation axis)	rotor_interdistance	10	m

TABLE 3.9: RM1 MODEL COMPLEXITY 3

Inputs description	Variable Name	Value	Units
Power Coefficient	cp	See Table 3.10	-
Trust Coefficient	ct	See Table 3.10	-
Power and Trust Curves' Velocity	cp_ct_velocity	See Table 3.10	m
Cut-in Velocity	cut_in_velocity	0.5	m/s
Cut-out Velocity	cut_out_velocity	3	m/s
Number of Rotor	number_rotor	2	-
Rotor Horizontal Interdistance (direction perpendicular to the rotation axis)	rotor_interdistance	10	m

TABLE 3.10: RM1 CP/CT CURVES*

Velocity	cp	ct
0.5	0.025	0.024
1	0.621	0.502
1.5	0.558	0.464
2	0.489	0.419
2.5	0.233	0.219
3	0.131	0.127

* only a subset of the data is presented; the full dataset can be found in the verification data and Figure 3.1

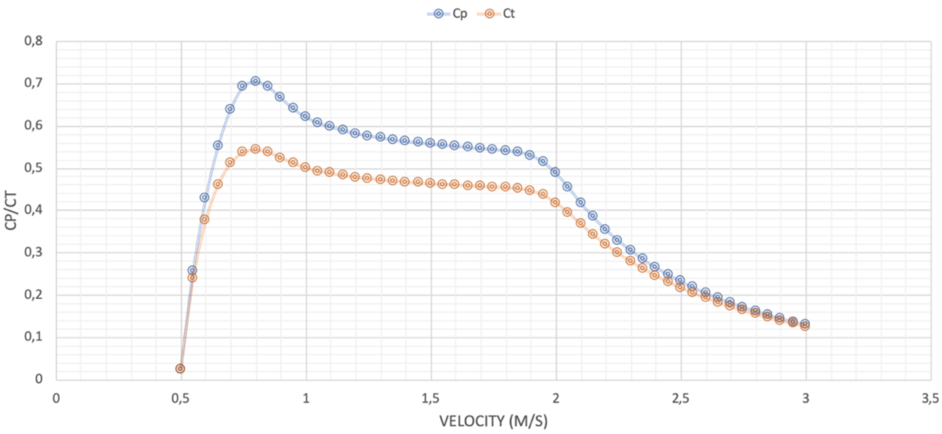


FIGURE 3.1: CP/CT CURVES

3.2.4.2 Wave Case

The Machine Characterisation module has three levels of complexity; each complexity level's data requirements are given in the following tables.

TABLE 3.11: RM3 GENERAL INPUTS

Inputs description	Variable Name	Complexity	Value	Units
Connector Type	connector_type	all	"wet"	-
Floating Machine	floating	all	true	bool
Rated Capacity	rated_capacity	all	286.0	kW
Constant Power Factor	constant_power_factor	all	1.0	-
Machine Unit Cost	machine_cost	all	2.000.000	EUR
Material Name	materials.material_name	all	"undefined"	-
Material Quantity	materials.material_quantity	all	1000000	kg
Max Installation Depth	max_installation_water_depth	all	-40	m
Min Installation Depth	min_installation_water_depth	all	-100	m
Min Interdistance X direction (rotation axis)	min_interdistance_x	all	600	m
Min Interdistance Y direction (perperndicular to rotation axis)	min_interdistance_y	all	600	m
Target Fundation Type	preferred_fundation_type	all	"drag_embedded"	-
Rated Voltage	rated_voltage	all	11.000	V

TABLE 3.12: RM3 DIMENSION INPUTS

Inputs description	Variable Name	Complexity	Value	Units
Beam Wet Area	beam_wet_area	3	-	m^2
Characterisitc Dimension	characteristic_dimension	all	6.0	m
Draft	"draft": 0.0,	all	0.0	m
Dry frontal area	dry_frontal_area	3	0	m^2
Dry profile	dry_profile	all	-	-
Footprint Radius	footprint_radius	all	20	m
Total Height	height	all	42	m
Hub heigth	hub_heigth	none	-	m
Total Length	length	all	6.0	m
Total Mass	mass	all	1000000.0	kg
Submerged volume	submerged_volume	all	1000.0	m^3
Wet Area	wet_area	all	-	m^2
Wet Frontal Area	wet_frontal_area	3	-	m^2
Wet Profile	wet_profile	all	-	-
Total Width	width	all	6.0	m

TABLE 3.13: RM3 MODEL COMPLEXITY 1

Inputs description	Variable Name	Value	Units
Capture Width Ratio (CWR)	capture_width_ratio	0.31	-
Machine Archetype	machine_archetype	"point_absorber"	-

TABLE 3.14: RM3 MODEL COMPLEXITY 2

Inputs description	Variable Name	Value	Units
Capture Width Ratio (CWR)	capture_width_ratio	see Table 3.19	-
Hs (CWR)	hs_capture_width	see Table 3.19	m
Tp (CWR)	tp_capture_width	see Table 3.19	s
Wave Direction (CWR)	wave_angle_capture_width	0	deg
Machine Archetype	machine_archetype	"point_absorber"	-
Power-Take-Off Average Damping	pto_damping	1000000	N/(m/s)

TABLE 3.15 RM3 MODEL COMPLEXITY 3

Inputs description	Variable Name	Value	Units
Wave Frequencies	wave_frequency	[0.5,1, 1.5, 2,2.5, 3, 3.5, 4,4.5, 5]	rad/s
Wave Direction	wave_direction	[0]	deg
Heading Angle Span	heading_angle_span	Deg	0
Generate Array Interaction Matrix	get_array_mat	True	bool
Degree of Freedom (DOF)	dofs	["Surge","Heave","Pitch"]	-
Shared DOF	shared_dof	[1,0,1,0,1,0]	-

Total Number of Generalised DOF	ndof	4	-
Angular Discretisation of Inscribing Cylinder	cyl_theta	10	-
Vertical Discretisation of Inscribing Cylinder	cyl_zeta	11	-
Mechanical Joints Definition for Multibody Systems	joints	Joint 1 see	-
Bodies Description	bodies	Body 0 see Table 3.16 Body 1 see Table 3.17	-
Water Depth	water_depth	100	m
PTO Damping	pto_damping	1.2e6	N/(m/s) or Nm/(rad/s)
Mooring Stiffness	mooring_stiffness	10000.0	N/m or Nm/rad
Additional Damping	additional_stiffness	0	N/(m/s) or Nm/(rad/s)
Additional Stiffness	additional_damping	0	N/m or Nm/rad
Capture Width Ratio (CWR)	capture_width_ratio	see Table 3.19	-
Hs (CWR)	hs_capture_width	see Table 3.19	M
Tp (CWR)	tp_capture_width	see Table 3.19	s
Wave Direction (CWR)	wave_angle_capture_width	0	deg
Wave Spectra: Directional Spreading	wave_spectral:angular_spreading_factor	0	-
Wave Spectra: Peak Enhancement Factor	wave_spectral:peak_enhancement_factor	3.3	-
Wave Spectra: Spectrum Shape	wave_spectral:spectrum_type	"JONSWAP"	-

TABLE 3.16: RM3 BODY 0 DEFINITION: SPAR

Inputs description	Variable Name	Value	Units
ID	ID	0	-
Moment of Inertia Tensor	MoI	[[94419615,0,0], [0,94497091,0], [0,0,28542225]]	kg m²
Body Mass	mass	878300	kg
Center of Gravity	cog	[0,0,-21.79]	m
Body Coordinate System Orientation in Euler Angles	axis_angles	[0,0,0]	deg
Mesh Name	mesh	"Spar.dat"	-
Mesh Format	mesh_format	"Nemoh"	-
Mesh Vertexes and Panels	mesh_raw	[]	m

TABLE 3.17: RM3 BODY 1 DEFINITION: FLOATER

Inputs description	Variable Name	Value	Units
ID	ID	1	-
Moment of Inertia Tensor	MoI	[20907301,0,0], [0,21306090,0], [0,0,37085481]]	kg m²
Body Mass	mass	727010	kg
Center of Gravity	cog	[0,0,-0.72]	m
Body Coordinate System Orientation in Euler Angles	axis_angles	[0,0,0]	deg
Mesh Name	mesh	"Floater.dat"	-
Mesh Format	mesh_format	"Nemoh"	-
Mesh Vertexes and Panels	mesh_raw	[]	m

TABLE 3.18: RM3 JOINTS DEFINITION

Inputs description	Variable Name	Value	Units
ID	ID	0	-
Parent ID	parent	0	-
Child ID	child	1	-
Point of Application	point_of_application	[0,0,0]	m
Direction	joint_direction	[0,0,1]	m
Joint Type	type	"prismatic"	-

TABLE 3.19: MACHINE CWR AT COMPLEXITY 2

	Te													
Hs	4.5	5.5	6.5	7.5	8.5	9.5	11	12	13	14	15	16	17	18
0.25	0	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0
0.75	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0
1.25	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0
1.75	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0
2.25	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0
2.75	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0
3.25	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0
3.75	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0	0
4.25	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0	0
4.75	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0
5.25	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0
5.75	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0
6.25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0
6.75	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0
7.25	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0
7.75	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0
8.25	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0

3.3 ENERGY CAPTURE (EC)

3.3.1 User flow and experience

The main purpose of the Energy Capture module is to estimate the raw power production for an array of tidal or wave energy converters. The user has two main options:

- Verification – given an array layout, the user would like to estimate the potential power production
- Optimisation – given the installation area, the user wants to know the layout that maximises power production.

In order to design the array layout, the user must have information about the site conditions and the machine properties.

The EC modules' main outputs are the array layout, the Annual Energy Production(AEP) of the array and the devices, the power performance of each device in each site condition and the hydrodynamic efficiency (q-factor) of the array and the single devices (q-factor).

3.3.2 User Stories

There are two main user stories for the Energy Capture module, and this can be further specified for the type of machine and the project complexity. The user stories can be expressed as follows:

1. As a *project* or *device developer*, I would like to verify the power performances of a specific array layout of either tidal or wave energy converters.

2. As a *project* or *device developer*, I would like to identify the maximum power performances of an array of either tidal or wave energy converters without a specific layout, given the installation area and some constraints associated with the devices' placement.

3.3.3 Definition of the Verification Cases

The verification cases for the EC module only cover one of the user stories, leaving out the array layout optimisation case, since there was no comparison data available for the optimisation. The six verification cases are summarised in Table 3.20.

TABLE 3.20: FEATURES AND TOTAL NUMBER OF VERIFICATION CASES FOR EC

Feature	VC1	VC2	VC3	VC4	VC5	VC6
Technology	Tidal	Tidal	Tidal	Wave	Wave	Wave
Complexity level	1	2	3	1	2	3
Machine Name	RM1	RM1	RM1	RM3	RM3	RM3

3.3.4 Collection of data required

3.3.4.1 Tidal Case

The Energy capture module has three levels of complexity; the data requirements for both machine and site for each complexity level is given in the following tables.

TABLE 3.21: RM1 MACHINE DATA

Inputs description	Variable Name	Complexity	Value	Units
Rotor Diameter	main_dim_device	1	20.0	m
Rotor Diameter	rotor_diameter	2-3	20.0	m
Rated Power	rated_pow_device	all	1100000	W
Power Coefficients	cp	1-2	0.554	-
Power Coefficients	cp	3	Given in Table 3.22	-
Trust Coefficients	ct	3	Given in Table 3.22	-
Hub Height	hub_height	2-3	30.0	m
Floating	floating	2-3	false	bool
Cut in/out velocities	[cut_in_velocity, cut_out_velocity]	2-3	[0.5,3.0]	m/s
Number of Rotors	number_rotor	2-3	2	-
Rotor Interdistance	rotor_interdistance	2-3	10	m

TABLE 3.22: RM1 CP/CT CURVES*

U	cp	ct
0.5	0.025	0.024
1	0.621	0.502
1.5	0.558	0.464
2	0.489	0.419
2.5	0.233	0.219
3	0.131	0.127

* only a subset of the data is presented; the full dataset can be found in the verification data and Figure 3.2.

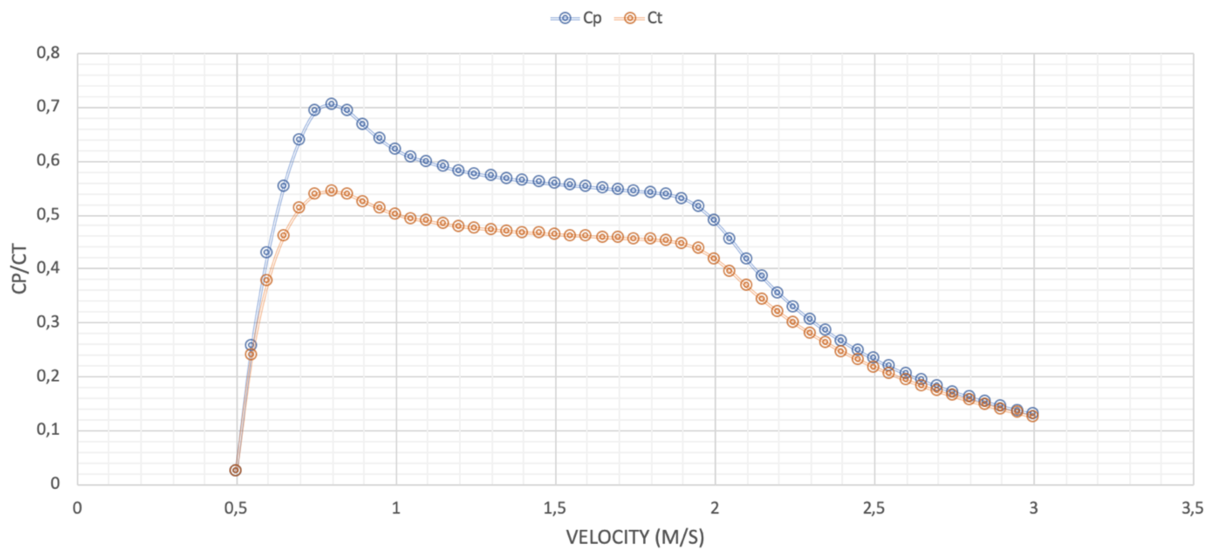


FIGURE 3.2: CP/CT CURVES

TABLE 3.23: RM1 SITE DATA

Inputs description	Variable Name	Complexity	Value	Units
Lease Area Vertex (Easting, Northing)	loc_position	all	[[533883.1842, 5234048.363], [533022.3238, 5234555.751], [533422.5557, 5235254.904], [534284.8078, 5234743.342]]	UTM
Average Velocity Magnitude	loc_resource	1	1.537	m/s
Average Velocity Vector (Easting, Northing)	velocity_field	2	[1.287,0.551]	m/s
Bathymetry	bathymetry	2-3	50.0	m
Turbulence Intensity	TI	3	0.3	-
Vertical Velocity Profile Power Law Exponent	power_law_exponent	3	0.143	-
Manning Number	soil_characteristic	3	0.005	m
Easting Velocity Component	U	3	See Table 3.7	m/s
Northing Velocity Component	V	3	See Table 3.7	m/s
Probability of Occurrence	p		See Table 3.7	%

TABLE 3.24: PROBABILITY OF OCCURENCE AND SPACE AVERAGE VELOCITY VECTOR

Probability (%)	U - Easting (m/s)	V - Northing (m/s)
0.09	-0.4445	-2.6805
0.32	-0.5281	-2.4259
0.85	-0.5281	-2.4259
5.98	-0.6877	-2.2272
3.73	-0.7628	-2.1371
10.96	-0.7780	-1.9445
7.23	-0.8191	-1.8242
15.07	-0.8583	-1.6257
7.45	-0.8218	-1.5226
6.80	-0.7621	-1.3186
10.40	-0.6578	-1.2191
3.41	-0.5579	-1.0197
6.15	-0.4500	-0.9108
3.35	-0.3506	-0.7006
6.96	-0.3494	-0.6163
1.75	-0.1999	-0.3993
6.45	-0.1824	-0.3086
1.44	-0.1009	-0.1303
1.57	-1.2626	-2.4059

TABLE 3.25: FARM DEFINITION INPUTS

Inputs description	Variable Name	Complexity	Value	Units
Number of Devices	number_devices	all	10	-
Device Positions	layout	all	See Table 3.9	UTM
Orientation Angle	orientation_angle	all	0.0	Deg
Farm Layout Type	layout_type	all	'Verification'	-

TABLE 3.26: FARM LAYOUT

Device ID (-)	U - Easting (m)	V - Northing (m)
0	533811.6516	5234315.113
1	533705.8036	5234381.605
2	533599.9556	5234448.097
3	533494.1077	5234514.59
4	533388.2597	5234581.082
5	533282.4118	5234647.574
6	533599.7023	5234918.27
7	533705.5503	5234851.778
8	533811.3983	5234785.286
9	533917.2462	5234718.794

3.3.4.2 Wave Case

The Energy capture module has three levels of complexity; the data requirements for both machine and site for each complexity level are given in the following tables [1].

It is important to notice that the hydrodynamic data for the complexity 3 case is different from the data used in the Sandia report [6]. The results presented in the Sandia report are based on a hydrodynamic model that does not have a sufficient number of wave frequency. This deficit influences negatively the calculation of the interaction between devices; therefore, it has been decided to create a more accurate model for the task.

TABLE 3.27: RM3 MACHINE DATA*

Inputs description	Variable Name	Complexity	Value	Units
Characteristic Length	main_dim_device	1-2	20.0	m
Rated Power	rated_pow_device	all	286000	W
Machine Type	machine_archetype	1-2	'point_absorber'	-
Capture Width Ratio	device_capture_width_ratio	1	0.19	-
Capture Width Ratio Matrix	device_capture_width_ratio	2	See Table 3.19	-
Hs – CWR	hs_capture_width	2	See Table 3.19	m
Tp – CWR	tp_capture_width	2	See Table 3.19	s
Direction – CWR	wave_angle_capture_width	2	0	deg

* The data for the machine at complexity 3 is not given for readability reason. The dataset can be found in the related verification scenario.

TABLE 3.28: MACHINE CWR AT COMPLEXITY 2

Hs \ Te	4.5	5.5	6.5	7.5	8.5	9.5	11	12	13	14	15	16	17	18
0.25	0	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0
0.75	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0
1.25	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0
1.75	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0
2.25	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0
2.75	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0
3.25	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0
3.75	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0	0
4.25	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0	0
4.75	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0
5.25	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0
5.75	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0
6.25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0
6.75	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0
7.25	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0
7.75	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0
8.25	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0

TABLE 3.29: RM3 SITE DATA*

Inputs description	Variable Name	Complexity	Value	Units
Lease Area Vertex (Easting, Northing)	loc_position	all	[393550,4521100], [391810,4522035], [393730,4525490], [395490,4524555]	UTM
Average Energy Flux	loc_resource	1	36060	W/m
Bathymetry	bathymetry	3	90.0	m
EJDP	scatter_diagram	2-3	See Table 3.30	-
Tp - EJDP	tp	2-3	See Table 3.30	s
Hs -EJDP	hs	2-3	See Table 3.30	m
Direction - EJDP	dirs	3	0	Deg

TABLE 3.30: EJDP HS/TP

Hs \ 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
0.3	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
0.8	0%	0%	1%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.3	1%	2%	5%	4%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%
1.8	1%	2%	5%	7%	5%	1%	1%	0%	0%	0%	0%	0%	0%	0%
2.3	0%	2%	4%	5%	6%	3%	1%	1%	0%	0%	0%	0%	0%	0%
2.8	0%	1%	3%	3%	4%	4%	3%	1%	1%	0%	0%	0%	0%	0%
3.3	0%	0%	1%	1%	1%	1%	1%	0%	0%	1%	0%	0%	0%	0%
3.8	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%
4.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
4.8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
5.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
5.8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
6.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
6.8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
7.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
7.8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
8.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

TABLE 3.31: FARM DEFINITION INPUTS

Inputs description	Variable Name	Complexity	Value	Units
Number of Devices	number_devices	all	10	-
Device Positions	layout	all	See Table 3.32	UTM
Orientation Angle	orientation_angle	all	0.0	Deg
Farm Layout Type	layout_type	all	'Verification'	-

TABLE 3.32: FARM LAYOUT

Device ID (-)	U - Easting (m)	V - Northing (m)
0	393359.9919	4523067.043
1	393429.76	4522366.509
2	393499.5281	4521665.974
3	394597.5413	4524174.685
4	393908.9985	4524321.398
5	393978.7666	4523620.864
6	393290.2238	4523767.577
7	392741.2172	4522513.222
8	394048.5347	4522920.33
9	393839.2304	4525021.933

3.4 ENERGY TRANSFORMATION (ET)

3.4.1 User flow and experience

The Energy Transformation Module can design and assess four main sub-systems of the PTO:

- **Mechanical Transformation**: Designs the mechanical parts and performs the calculation of the PTO mechanical efficiency and loads knowing:
  - The PTO technology from the User
  - The resource from the Site Characterisation module
  - The absorbed energy and the device motion from the Energy Capture tool
  - The device characteristics from the Machine Characterisation module
  - The control strategy (passive control or user-defined)
  - The component database
- **Electrical Transformation**: Designs the electrical parts and computes the generator efficiency and loadings, knowing the mechanical PTO power and operation range.
- **Grid Conditioning**: Designs the components for grid conditioning electrical power, mainly selects the power converter, computes its efficiency, and the electrical output power.
- **Control Strategy**: Dedicated to traducing device motions and loadings to specific velocity distributions to be accounted for in the conversion chain.

Finally, the ET module outputs provide information about cost, efficiency, reliability and mass of the different energy transformation objects.

3.4.2 User Stories

There are four user stories that cover both technologies (wave and tidal) and array or device level.

1. As a *technology developer*, I want to *analyse the PTO of a tidal turbine designed for a specific location at an early stage of technology development*. The mechanical, electrical and grid transformations will be modelled in a simplified manner. The PTO will use the default passive controller.
2. As an *investor*, I want to *analyse the PTO of a tidal turbine in an array designed for a specific location at an intermediate stage of technology development*. The mechanical and electrical transformations will be modelled with a gearbox and a squirrel cage induction generator (SCIG) generator, respectively, whereas the power electronics will consist of a back-to-back converter. The PTO will use the default passive controller.
3. As a *technology developer*, I want to *analyse the PTO of a single unit of a floating OWC buoy designed for a specific location at an early stage of technology development*.
4. As an *investor*, I want to *analyse the PTO of a floating OWC buoy in an array designed for a specific location at an intermediate stage of technology development*. The mechanical and electrical transformations will be modelled with an Impulse Air Turbine and a SCIG generator, respectively, whereas the power electronics will consist of a back-to-back converter. The PTO will use the default passive controller.

3.4.3 Definition of the Verification Cases

Four verification cases have been devised in ET, as shown in Table 3.33:

TABLE 3.33: ET FEATURES AND VERIFICATION CASES

Feature	VC1	VC2	VC3	VC4
Technology	Tidal	Tidal	Wave	Wave
Mechanical transformation	Simplified	Gearbox	Wells turbine	Impulse tur.
Electrical transformation	Simplified	SCIG	Simplified	SCIG
Grid transformation	Simplified	B2B	Simplified	B2B
Control	Passive	Passive	Passive	Passive
ET Complexity level	1	2	1	2
Number of devices	1	10	1	10

Key - SCIG: Squirrel Cage Induction Generator; B2B: Back-to-back power converter

The complexity level in Table 3.3 is the global ET complexity level. Each transformation stage will have its own complexity level. In the verification cases VC1-VC4, the complexity of each stage will be 1 when it is "simplified" and 2 when the name of the stage appears (Gearbox, SCIG, B2B etc.).

User-defined control is only available for Mechanical transformation at complexity level 3 (default data was used for complexity 2 and user defined data, from catalogue, was used for complexity 3).

Variations of VC2-VC4 may be run to verify the optimal sizing of the specific PTO objects. This should be implemented by defining a range of a single design parameter for the PTO object (i.e. mechanical, electrical and grid transformation) and the objective function (i.e. cost ratio or reliability ratio).

It is worthwhile mentioning that the 4 VCs do not explore all potential combinations of object types, complexity levels, ocean technologies and basic features but comprise the minimum case number to cover the full extent of Software Routes.

The 4 VCs can be grouped into four independent scenarios for the verification of ET Features, depending on the ocean energy technology (wave or tidal) and the project scope (single device or array):

TABLE 3.34: VERIFICATION SCENARIOS

Verification Scenarios	Device	Array
Tidal Energy	RM1 x 1 – VC1	RM1 x 10 – VC2
Wave Energy	RM3 x 1 – VC3	RM3 x 10 – VC4

The verification scenarios are based on Sandia's Reference Model 1 and 3, which input values were used whenever possible. However, for the ET tool verification purposes, some parameters and transformation objects have been modified in each VC.

3.4.4 Collection of data required

ET module will obtain inputs from 3 different resources:

- External modules
- User inputs from the GUI
- Component Database (Catalogue)

INPUTS FROM EXTERNAL MODULES

Depending on the complexity level and technology, different inputs will be needed:

- The resource from the Site Characterisation module
- The absorbed energy and the device motion from the Energy Capture tool
- The device characteristics from the Machine Characterisation module

In standalone mode, these inputs will be uploaded to the ET study through 3 independent json files

USER INPUTS FROM THE GUI

The user will set basic information about the ET study and provide the main inputs of each transformation stage depending on the complexity level and technology.

- **Study**: Name, description and standalone mode (yes/no)
- **General inputs**: Parallel PTOs and shutdown flag
- **Mechanical inputs**: Main mechanical transformation parameters as power, type of conversion, transformation ratio, etc.
- **Electrical inputs**: Main generator parameters like rated power, voltage, frequency, etc.
- **Grid inputs**: Main power electronics parameters like rated power, DC-link voltage, switching frequency, etc.
- **Control inputs**: Control type, basic control variables (n sigma and bins).

Complexity 1 is the simplest case, and very few variables will be modifiable by the user. The rest are fixed internally.

The specific User inputs for each verification case are shown in the tables below:

TABLE 3.35: INPUTS FOR CHARACTERISATION OF THE TIDAL PTO – LOW COMPLEXITY (VC1)

Parameters required	Source of Data	Additional Information / input value
Project level		
Number of devices	EC	1
Technology	MC	Tidal TEC
ET complexity level	User/GUI	1
Environmental Conditions	EC/SC	Vc/ Occurrence
Device level		
Number of PTOs per device (number of rotors in tidal, dof_ptos)	MC	2

Parameters required	Source of Data	Additional Information / input value
Shutdown Flag (minimum number of PTOs to have the device ON)	User/GUI	1
Device Performance (captured power)	EC	550
Cp (power coefficient)	MC	0.37
Mechanical Conversion Type	User/GUI	Simplified-cpx1
Electrical Conversion Type	User/GUI	Simplified - cpx1
Grid Conditioning Type	User/GUI	B2B-simplified- cpx1
PTO level		
Main dimension (rotor diameter)	EC	20 [m]
Mechanical Conversion Size (Max Power)	User/GUI	550000 [W]
Mechanical Transmission Ratio	User/GUI	53 [-]
Electrical Conversion Rated Power	User/GUI	550000 [W]
Grid Conditioning Rated Power	User/GUI	550000 [W]
Passive Control n sigma	User/GUI	5
Passive control bins	User/GUI	500

TABLE 3.36: INPUTS FOR CHARACTERISATION OF THE TIDAL PTO – MID COMPLEXITY (VC2)

Parameters required	Source of Data	Additional Information / input value
Project level		
Number of devices	EC	10
Technology	MC/SC	Tidal
ET complexity level	User/GUI	2
Environmental Conditions	SC/EC	[Tp/Occ /Vcc]
Device level		
Number of PTOs per device (number of rotors in tidal, dof_ptos)	MC	2
Ct: inverse of the mean rotational speed of the turbine rotor	MC	0.82
Cp (power factor)	MC	0.37
Vc cut-in/cut-out	MC	0.5 / 3
Shutdown Flag (minimum number of PTOs to have the device ON)	User/GUI	1
Device Performance	EC/MC	TSR = 5.8
Mechanical Conversion Type	User/GUI	Gearbox-cpx2
Electrical Conversion Type	User/GUI	SCIG-cpx2
Grid Conditioning Type	User/GUI	B2B-cpx2
PTO level		
Rotor diameter	EC	20 [m]
Gearbox maximum power	User/GUI	550000 [W]
Gearbox transmission ratio	User/GUI	53
SCIG rated power	User/GUI	550000 [W]
SCIG rms voltage	User/GUI	690 [V]
SCIG nominal frequency	User/GUI	60 [Hz]
SCIG inductance	User/GUI	0.0005 [Hr]
SCIG resistance	User/GUI	0.0001 [ohm]
SCIG pole pairs	User/GUI	5
SCIG maximum to nominal torque	User/GUI	2
SCIG maximum to nominal voltage	User/GUI	1.725

Parameters required	Source of Data	Additional Information / input value
SCIG conversion class (for life calculation)	User/GUI	Class F
B2B2Level rated power	User/GUI	550000 [W]
DC link voltage	User/GUI	1200 [V]
Switching frequency	User/GUI	5000 [Hz]
Grid rms voltage	User/GUI	690 [V]
Grid frequency	User/GUI	50 [Hz]
B2B2Level resistance	User/GUI	0.0001 [ohm]
B2B2Level inductance	User/GUI	0.001 [Hr]
Required cosphi	User/GUI	0.95
Passive Control n sigma	User/GUI	5
Passive control bins	User/GUI	500

TABLE 3.37: INPUTS FOR CHARACTERISATION OF THE WAVE PTO – LOW COMPLEXITY (VC3)

Parameters required	Source of Data	Additional Information / input value
Project level		
Number of devices	EC	1
Technology	MC/SC	Wave
Complexity level	User/GUI	1
Environmental Conditions	SC	[Hs/Tp/Occ
Device level		
Number of PTOs per device (parallel_ptos)	User/GUI	1
Shutdown Flag (minimum number of PTOs to have the device ON)	User/GUI	1
Device Performance	EC/MC	100 kW [100 kW-Captured power and PTO damping-565000]
Mechanical Conversion Type	User/GUI	AirTurbine-cmx2
Electrical Conversion Type	User/GUI	Simplified-cmx1
Grid Conditioning Type	User/GUI	Simplified-cmx1
PTO level		
Turbine_Type	User/GUI	Wells
Turbine_Diameter	User/GUI	1 [m]
Turbine_OWC_Surface	User/GUI	20 [m²]
Turbine_transmission_ratio	User/GUI	3:1 [-]
Electrical Conversion Rated Power	User/GUI	100000 [W]
Grid Conditioning Rated Power	User/GUI	100000 [W]
Passive Control n sigma	User/GUI	5
Passive control bins	User/GUI	500

TABLE 3.38: INPUTS FOR CHARACTERISATION OF THE TIDAL PTO – MID COMPLEXITY (VC4)

Parameters required	Source of Data	Additional Information / input value
Project level		
Number of devices	EC	10
Technology	MC/SC	Wave
ET complexity level	User/GUI	2
Environmental Conditions	SC	[Hs/Tp/Occ]

Parameters required	Source of Data	Additional Information / input value
Device level		
Number of PTOs per device (parallel PTOs)	User/GUI	1
Shutdown Flag (minimum number of PTOs to have the device ON)	User/GUI	1
Device Performance	EC/MC	[100 kW Captured power and damping 565000]
Mechanical Conversion Type	User/GUI	Air Turbine-cmx2
Electrical Conversion Type	User/GUI	SCIG-cmx2
Grid Conditioning Type	User/GUI	B2B-cmx2
PTO level		
Turbine_Type	User/GUI	Impulse
Turbine_Diameter	User/GUI	1 [m]
Turbine_OWC_Surface	User/GUI	20 [m2]
Mechanical transformation ratio: Relationship between the mechanical rotation obtained from the mechanical transformation and the speed of the generator shaft value	User/GUI	[2]
SCIG rated power	User/GUI	100000 [W]
SCIG rms voltage	User/GUI	690 [V]
SCIG nominal frequency	User/GUI	60 [Hz]
SCIG inductance	User/GUI	0.0005 [Hr]
SCIG resistance	User/GUI	0.0001 [ohm]
SCIG pole pairs	User/GUI	5
SCIG maximum to nominal torque	User/GUI	2
SCIG maximum to nominal voltage	User/GUI	1.725
SCIG conversion class (for life calculation)	User/GUI	Class F
B2B2Level rated power	User/GUI	100000 [W]
DC link voltage	User/GUI	1200 [V]
Swiching frequency	User/GUI	5000 [Hz]
Grid rms voltage	User/GUI	690 [V]
Grid frequency	User/GUI	50 [Hz]
B2B2Level resistance	User/GUI	0.0001 [ohm]
B2B2Level inductance	User/GUI	0.001 [Hr]
Required cosphi	User/GUI	0.92
Passive Control n sigma	User/GUI	5
Passive control bins	User/GUI	500

CATALOGUE INPUTS

Apart from external inputs and user inputs, there are many other data needed for the ET module's detailed computation; especially specific parameters of each component in the transformation stages.

As this data is not usually known by mid-level users, default data is included in a catalogue.

Catalogue parameters are used by all transformation stages in complexities 2 and 3 as the models used are the same. These parameters will be modifiable only in complexity 3.

3.5 ENERGY DELIVERY (ED)

3.5.1 User flow and experience

The main purpose of the Energy Delivery module is to design the electrical network to transmit power from devices to shore, including the:

- Array network – cables between Ocean Energy Converters (OEC)
- Collection point (CP), which can be a substation with voltage transformation or a passive hub.
- Transmission cable to the Onshore Landing Point (OLP)

The design is based on user choices, design parameters from other modules, and a catalogue of typical electrical components.

In standalone mode, the user first sets up a study before entering inputs for the site, device, array, and configuration options. Once these inputs are complete, the user can run the design process and then view the results.

The main outputs are a network design, the energy and power delivered to shore and network losses, a total cost and bill of materials for the electrical components used, plus a hierarchy of how they are connected.

3.5.1.1 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 may require further updates and testing to the business logic, back end, or GUI or may require updates to other modules.

1) At complexity level 1, the module now allows designing and evaluating networks for single devices. For the single device case, direct connection to the shore is the network configuration considered. To evaluate this case, enter the number of devices to be 1 and the array spacing to be 0 m. This has been fully implemented but is not a part of the deployed tool.
2) Exclusion zones in site inputs at complexity levels 2/3. The input will be a list of coordinates of the polygon that constitutes the exclusion zone in both the lease area and the export cable corridor. This has already been implemented in the Business Logic but not in the Back End and the GUI.
3) The options to include (or not) the onshore infrastructure cost has now been implemented in a different way at all complexity levels. The options include entering 0 for the Onshore infrastructure cost, not to consider these costs or to enter an estimate of the cost if known beforehand, or leaving blank when a cost function is used to evaluate the onshore infrastructure cost.
4) When the tool is running in integrated mode with the other modules, the user will select one network to take forward for further design and analysis. Note that this feature is not yet implemented in the standalone mode.

3.5.2 User Stories

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

2. **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 deployment.
3. **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.

3.5.3 Definition of the Verification Cases

A set of verification cases were developed to cover the range of functionalities of the ED module. As noted above, the calculation logic is agnostic to the technology type (WEC/TEC) but does depend on whether the device is fixed or floating. A range of device ratings and array sizes were considered to test the typical range of electrical components required in an array. These were aligned with the US DoE 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.

The key parameters and values considered are listed in Table 3.39. 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 set of 15 cases is listed in Table 3.40, noting that verifiers were only expected to test a subset of these cases as there is significant overlap between them.

TABLE 3.39: KEY PARAMETERS VARIED IN VERIFICATION CASES WITH VALUES CONSIDERED

Parameter	Values considered
▫ Device rated power	▫ Small, 100 kW ▫ Medium, 286 kW (=RM3) ▫ Large, 1.1 MW (=RM1)
▫ Number of devices in Array	▫ Single device (=RM) ▫ Small, 5 devices ▫ Medium, 10 devices (=RM) ▫ Large, 50 devices (=RM)
▫ Network topology	▫ N/A for low complexity ▫ Direct to shore ▫ Radial ▫ Radial with transmission CP ▫ Single-cluster star ▫ Multi-cluster star ▫ Multi-cluster star with transmission CP
▫ Bathymetry	▫ N/A for low complexity ▫ Simple (uniform soil type) ▫ With obstacles (different soil types) ▫ RM1 trapezoidal channel ▫ RM3 site bathymetry

TABLE 3.40: LIST OF VERIFICATION CASES FOR ENERGY DELIVERY

Case	Complexity	Fixed/ floating	Network topology	Array size	Device power	Total array power (kW)	Installation method	Bathymetry file type	Like cases
1.1.	CPX1 Simplified	floating	n/a (radial)	Medium	Medium	3,000	n/a	n/a	2.2
1.2.	CPX1 Simplified	fixed	n/a (radial)	Large	Large	55,000	n/a	n/a	2.11
2.1.	CPX2/3 Detailed	fixed	direct to shore	Small	Small	500	dredging	simple	
2.2.	CPX2/3 Detailed	floating	radial	Medium	Medium	3,000	None	RM3	1.1, 2.12
2.3.	CPX2/3 Detailed	fixed	radial	Medium	Large	11,000	None	RM1	2.13
2.4.	CPX2/3 Detailed	fixed	radial with transmission CP	Small	Medium	1,500	jetting	simple	
2.5.	CPX2/3 Detailed	fixed	radial with transmission CP	Large	Small	5,000	ploughing	simple	
2.6.	CPX2/3 Detailed	fixed	single-cluster star	Small	Large	5,500	cutting	simple	
2.7.	CPX2/3 Detailed	fixed	single-cluster star	Medium	Medium	3,000	dredging	with obstacles	
2.8.	CPX2/3 Detailed	floating	multi-cluster star	Medium	Large	11,000	seabed lay	simple	

Case	Complexity	Fixed/ floating	Network topology	Array size	Device power	Total array power (kW)	Installation method	Bathymetry file type	Like cases
2.9.	CPX2/3 Detailed	fixed	multi-cluster star	Large	Medium	15,000	jetting	simple	
2.10.	CPX2/3 Detailed	floating	multi-cluster star with trans. CP	Medium	Small	1,000	ploughing	with obstacles	
2.11.	CPX2/3 Detailed	fixed	multi-cluster star with trans. CP	Large	Large	55,000	seabed lay	simple	1.2
2.12.	CPX2/3 Detailed	floating	direct to shore	Single	Medium	300	None	RM3	2.2
2.13.	CPX2/3 Detailed	fixed	direct to shore	Single	Large	1,100	None	RM1	2.3

3.5.4 Collection of data required

Running the verification cases in the Energy Delivery module requires a set of input data, which were collated from several freely available sources as described below. In some cases, synthesised data sets have been produced where real data were not available.

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

- Site characteristics: bathymetry and seabed material.
- Device characteristics: Rated power, voltage, technology type.
- Array characteristics: Number of devices and typical spacing or coordinates of the array layout, histogram of total array power output.
- Catalogue of electrical components: cables, connectors, collection points.

There are also several user choices, such as the network configuration to be assessed or the preferred installation technique, but these do not require the collection of data for verification.

The data sets required are different for each set of Verification Cases, as shown in Table 3.41. As noted above, some of the VC were aligned to the US DoE RM1 and RM3 described in [1].

TABLE 3.41: DATA SOURCES FOR ENERGY DELIVERY VERIFICATION CASES

Data type	Verification Cases	Data used and source(s)
Site Characteristics	Low complexity (1.1, 1.2)	Not required
	RM1 tidal (2.3, 2.13)	Synthetic bathymetry created to match trapezoidal channel used for RM1. Sediment type not assessed for RM1; therefore, 'hard glacial till' was selected [14].
	RM3 wave (2.2, 2.12)	RM3 bathymetry and soil data from DTOcean2 example data [15]
	Other full complexity (2.1, 2.3-2.11)	Synthetic bathymetry and seabed material data created
Device Characteristics	RM1 tidal (1.2, 2.3, 2.13)	Fixed device, 1100kW at 33kV to match RM1, note that standard voltage used is slightly higher than the 30kV used in RM1
	RM3 wave (1.1, 2.2, 2.12)	Floating device, 300kW at 690V, similar to RM3
	Other full complexity (2.1, 2.3-2.11)	Synthetic devices at a range of power and export voltage levels
Array Characteristics	Low complexity (1.1, 1.2)	Array spacing and distance to shore to match RM1 and RM3 array layouts.
	RM1 tidal (2.3, 2.13)	Rectangular array of 10 devices† to match RM1, plus single RM1 device. Histogram of array power output for RM1, re-binned to suit ED requirements. Onshore landing point taken as halfway between rows 1 & 2 at edge of channel to match RM1.
	RM3 wave (2.2, 2.12)	Hexagonal array of 10 devices† to match RM3, plus single RM3 device. Histogram of nominal array power output. Onshore landing point from DTOcean2 example data [15]
	Other full complexity (2.1, 2.3-2.11)	Synthetic array layouts of 5, 10, and 50 devices. Synthetic histograms of array power output.

† Arrays of 50 devices were also created for RM1 & RM3, but not used in the verification cases

For all VCs, the same catalogue of electrical components was used, containing: static and dynamic (umbilical) cables; wet-mate and dry-mate connectors; collection point and transformer details. This catalogue is based upon the DTOcean2 example database [15], with additional synthesised components created as necessary to meet the requirements of the VC. An updated catalogue of generic electrical components is currently being created. This will be released as an open-source dataset and will also be available as part of the final DTOceanPlus suite of tools.

3.6 STATION KEEPING (SK)

3.6.1 User flow and experience

The main purpose of the Station Keeping module is to design and assess the mooring system, anchors and foundations of the devices and substation, including:

- Mooring lines for floating structure (design, ULS analysis and FLS analysis)
- Anchors (design and ULS analysis)
- Foundation for fixed structure (design and ULS analysis)

The design is based on user choices and inputs, design parameters from other modules, and a catalogue of typical line types and anchors.

In standalone mode, the user first sets up a study, providing a name. He/she then has to specify the input data by describing the characteristics of the site, the device and the analysis parameters regarding the mooring system, anchors and foundations.

In integrated mode, input data regarding the site and the device are imported from other modules.

The main outputs are the assessment of the mooring system, foundation and ancho r design, the total cost and bill of materials for the components used, a hierarchy of how they are connected. In order to ease the interface with commercial software, the mooring system description can be exported as a MAP++ data format file (https://map-plus-plus.readthedocs.io/en/latest/input_file.html).

3.6.2 User Stories

There are two main user stories for the SK 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 *design of the mooring system, anchors and/or foundations.*
2. **Full design mode:**
    a. As a *project developer*, I would like to assess and/or design the *mooring system, anchors and/or foundations.*

3.6.3 Definition of the Verification Cases

Five functionalities can be identified in order to assess the performance and accuracy of this module:

- **Automated design of foundation**: an estimate of the necessary dimensions of the foundation of a fixed device.
- **Automated design of anchor**: an estimate of the necessary dimensions of the anchors of the floating device.

- **Automated design of catenary mooring system**: an estimate of the necessary dimensions of the anchors of the floating device.
- **Mooring system assessment**: ULS and FLS analysis of the mooring lines of a floating device.
- **Foundation assessment**: ULS analysis of the foundation of a fixed device.
- **Anchor assessment**: ULS analysis of the anchors of a floating device.

Six Verification Cases (VC) have been defined in order to check those functionalities (see TABLE 3.42). The six VCs can be grouped into two independent **Verification Scenarios**:

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

TABLE 3.42: TOTAL NUMBER OF VERIFICATION CASES FOR SK

Inputs characteristics					Outputs to verify			
Case	Floating / Fixed	Wec / Tec	Catenary / Taut	Design: Auto / Manual	ULS analysis	FLS analysis	Mooring design	Foundation design
RM1-SK1	Fix	Tec	None	Auto	X			X
RM1-SK2	Fix	Tec	None	Auto	X			X
RM1-SK3	Fix	Tec	None	Manual	X			
RM3-SK1	Flo	Wec	C	Auto	X		X	X
RM3-SK2	Flo	Wec	T	Manual	X			X
RM3-SK3	Flo	Wec	T	Manual	X	X		X

3.6.3.1 Case RM1-SK1

The verification test case RM1-SK-1 is based on the Scenario RM1, with the following user story:

" The user is working within the project described by Scenario RM1. The user knows that the device RM1 is to be installed on the seabed. They know the main characteristics of the device RM1 (main dimensions, weight, rotor properties). They also know the type of soil the device is to be installed on: 'dense sand'. They would like to know what kind of foundation is the most appropriated for this situation and the main dimensions of this foundation."

This verification test case focuses on the following functionalities of the SK module:

- Modelling of fixed structure
- Modelling of tidal machine rotor
- Automatic selection of most suitable foundation type
- Automatic design of foundation dimensions

3.6.3.2 Case RM1-SK2

The verification test case RM1-SK-2 is based on the Scenario RM1, with the following user story:

" The user is working within the project described by Scenario RM1. The user knows that the device RM1 is to be installed on the seabed. They know the main characteristics of the device RM1 (main dimensions, weight, rotor properties). They also know the type of soil the device is to be installed on 'dense sand'. After some predesign studies, they identified that the foundation type they would like to use is a pile. They would like to know the main dimensions of this foundation and its total cost."

This verification test case focuses on the following functionalities of the SK module:

- User-defined foundation type
- Automatic design of foundation dimensions
- Foundation cost calculation

3.6.3.3 Case RM1-SK3

The verification test case RM1-SK-3 is based on the Scenario RM1, with the following user story:

" The user is working within the project described by Scenario RM1. The user knows that the device RM1 is to be installed on the seabed. They know the main characteristics of the device RM1 (main dimensions, weight, rotor properties). They also know the type of soil the device is to be installed on 'dense sand'. After some predesign studies, they identified that the foundation type they would like to use is a pile. After some refined structure analysis studies, he knows the main dimensions of the pile. They would like to check if the design of the pile satisfies the criteria calculated by DTOceanPlus in this situation: lateral capacity, axial tension, axial compression and steel stress capacities."

This verification test case focuses on the following functionalities of the SK module:

- User-defined foundation dimensions
- Foundation criteria calculation

3.6.3.4 Case RM3-SK1

The verification test case RM3-SK-1 is based on the Scenario RM3, with the following user story:

" The user is working within the project described by Scenario RM3. The user knows that the device RM3 is to be moored. They know the main characteristics of the device RM3 (main dimensions, weight, hydrodynamics properties). They also know the type of soil at the site location: 'medium_dense_sand'. They would like to have a first estimate of an appropriate catenary mooring system design: number of mooring lines, mooring radius, chain diameter, type and size of anchor, and total cost.

This verification test case focuses on the following functionalities of the SK module:

- Modelling of a floating structure
- Automatic design of catenary mooring system
- Automatic selection of most suitable anchor type
- Automatic design of anchor dimensions

3.6.3.5 Case RM3-SK2

The verification test case RM3-SK-2 is based on the Scenario RM3, with the following user story:

" The user is working within the project described by Scenario RM3. The user knows that the device RM3 is to be moored. They know the main characteristics of the device RM3 (main dimensions, weight, hydrodynamics properties). They also know the type of soil at the site location: 'medium_dense_sand'. After some preliminary studies, they would like to run an ULS analysis for a defined taut mooring system made of nylon rope. They would like to have check if this system passes the ULS analysis criteria."

This verification test case focuses on the following functionalities of the SK module:

- Custom mooring system input
- ULS analysis

3.6.3.6 Case RM3-SK3

The verification test case RM3-SK-3 is based on the Scenario RM3, with the following user story:

" The user is working within the project described by Scenario RM3. The user knows that the device RM3 is to be moored. They know the main characteristics of the device RM3 (main dimensions, weight, hydrodynamics properties). They also know the type of soil at the site location: 'medium_dense_sand'. After some preliminary studies, they would like to run an FLS analysis for a defined taut mooring system made of nylon rope. They would like to have check if this system passes the FLS analysis criteria.

This verification test case focuses on the following functionalities of the SK module:

- Fatigue Limit State analysis (FLS)

3.6.4 Collection of data required

3.6.4.1 Case RM1-SKx

The device data necessary to run the verification cases are the following:

TABLE 3.43: RM1 DEVICE DATA

Inputs description	Value	Units
Type of technology	Fixed tidal machine with two rotors	-
Mass*	119700 (without the pile)	kg
Position of rotor 1	[x,y,z] = [0,-14,30]	m
Position of rotor 2	[x,y,z] = [0,14,30]	m
Rotor diameter	20	m
Rotor thrust coefficients	See Figure 3.2	-

*Note that the mass to be used in the SK module is the total mass of the device *without* the mass of the foundation. Here, by 'foundation', we mean the complete pile, comprising the buried part and the part above the seabed.

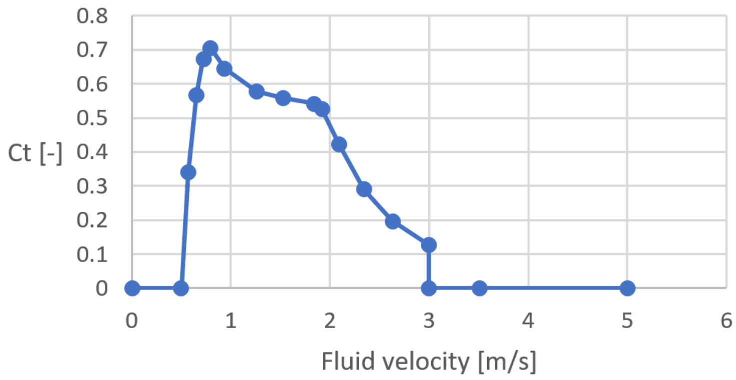


FIGURE 3.3: RM1 ROTOR THRUST COEFFICIENTS

The foundation data necessary to run the verification cases are the following:

TABLE 3.44: RM1 FOUNDATION DATA

Inputs description	Value	Units
Type of foundation	Pile	-
Type of pile tip (open or close)	open	-
Material	steel	-
Diameter of the pile	3.5	m
Height of the pile above seabed	30	m
Height of the pile below seabed	15	m
Thickness of pile	0.039	m

The environmental data necessary to run the verification cases are the following:

TABLE 3.45: RM1 ENVIRONMENTAL DATA

Inputs description	Value	Units
Water depth	50	m
Design Hs (100-years return period)	Assumed to be 8	m
Design Tp (100-years return period)	Assumed to be 10	s
Design Current velocity	2.85	m/s
Soil type	Assumed to be 'dense sand'	-

3.6.4.2 Case RM3-SKx

The device data necessary to run the verification cases are the following:

TABLE 3.46: RM3 DEVICE DATA

Inputs description	Value	Units
Type of technology	Floating wave energy converter machine	-
Mass	1665762	kg
Diameter of the main column	6.0	m
Submerged height of the main column	~40	m
Hydrodynamic data (radiation and diffraction)	Simplified 6-dofs model (assuming the surface float is fixed to the vertical column)	

The environmental data used for the ULS analysis are the following:

TABLE 3.47: RM3 ULS ENVIRONMENTAL DATA

Inputs description	Value	Units
Water Depth	70	m
100-year Significant Wave Height (Hs)	11.9	m
100-year Significant Wave Period (Tp)	17.1	s
100-year current speed	0.59	m/s
Seafloor composition	Sand/Clay	

The environmental data used for the FLS analysis are the following:

TABLE 3.48: RM3 FLS ENVIRONMENTAL DATA

Inputs description	Value	Units
Sea states discretization	Statistical discretization in terms of Hs and Wave directions	

The main mooring system data for the verification cases are the following:

TABLE 3.49: RM3 MAIN MOORING SYSTEM DATA

Inputs description	Value	Units
Number of mooring lines	3	-
Buoy (55 kN) per mooring line	1	-
Clump weight (10 tons) per mooring line	1	-
Mooring radius	~350	m
Mooring line segments	rope-nylon-chain	-
Rope segment length	~40	m
Nylon segment length	~270	m

Chain segment length	~40	m
Rope segment diameter	No data	m
Nylon segment diameter	0.146	m
Chain segment diameter	0.089	m
Anchor type	Anchor: 9-tonne Bruce® FFTS MK 4 anchor.	-
Estimated cost (mooring lines, anchors, buoys, clump weight and other ancillaries)	524 810	$
Estimated failure rate	0.02	1/year

3.7 LOGISTICS AND MARINE OPERATIONS (LMO)

3.7.1 User flow and experience

The main purpose of the Logistics and Marine Operations module is to design logistical solutions for the installation, operation and maintenance (O&M), and decommissioning phases of ocean energy projects. Logistic solutions consist of an operation plan and an optimal combination of vessels, equipment and ports that minimise the costs of each operation individually, reducing capital and operational expenditures simultaneously (CAPEX and OPEX).

For the different project phases, the logistical solutions include:

- Infrastructure solutions – an optimal selection of vessels, ports and support equipment to carry out the installation/O&M/decommissioning operations
- Operation plans – operation durations, weather contingencies, start dates, end dates.
- Operation costs – cost of operations, including vessel chartering costs, fuel costs, port costs and equipment costs. These costs are grouped into the installation, maintenance and decommissioning

The Logistic design is carried out based on the design outputs of upstream deployment design tools and project characteristics and preferences introduced by the user, and catalogues of vessels, port terminals, equipment and operations.

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 logistic design process and then view the results. The main outputs of the analysis are optimal installation, maintenance, and decommissioning plans, which include activity sequences, selected infrastructure, durations and costs.

3.7.1.1 Functionalities not fully implemented

There are a number of functionalities that have not been 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. The functionality to export the study.
2. The verification version of the LMO module required that the user-specified a “maintenance start date”, which corresponds to the commissioning date. The functionality to automatically use the commissioning date as the end of the installation phase (in case the installation phase is run) will be implemented.
3. The contributions of the waiting on weather, mobilisation, and transit, to the total operation durations, will be discretised and tabled for complexity Cpx3.

3.7.2 User Stories

There are three main user stories for the Logistics and Marine Operations module, corresponding to the three main project lifecycle phases, which can be expressed as follows:

1. **Simple mode (cpx1):**
   a. As a *project* or *technology developer*, I would like to get a *quick estimate* of the *installation, maintenance and decommissioning plans* that are specific to *my technology/project*, featuring a list of activities, expected durations, weather contingencies, costs, and infrastructure selection, in order estimate costs and support *component/project* design decisions.
2. **Full design mode (cpx2, cpx3):**
   a. As a *project* or *technology developer*, I would like to get *fully defined installation and decommissioning plans* that are specific to *my technology/project*, featuring a list of activities, expected durations, weather contingencies, costs, and infrastructure selection, in order estimate costs and support *component/project* design decisions.
   b. As a *project* or *technology developer*, I would like to get *maintenance plans* that are specific to *my technology/project, based on component reliability*, featuring the *list of O&M activities*, *expected durations*, *weather contingencies*, *costs*, *and infrastructure selection*, in order to support *component/project design decisions*.
   c. As a *policymaker*, I would like to obtain *high level installation, maintenance and decommissioning plans* featuring the list of activities in order to estimate total installation duration and assess whether environmentally damaging activities will be carried out.
   d. As a *project developer/technology developer/ policymaker*, I would like to visualize the *lifecycle phase plans displayed as Gant charts*.

3.7.3 Definition of the Verification Cases

Given that the logistic designs carried out within the LMO module require complex calculations and long computation times, a reduced number of Verification Cases was defined to test the module's functionalities. The module usability (i.e. GUI) will also be assessed qualitatively.

TABLE 3.50: VERIFICATION TESTS CONSIDERED FOR LMO

Test number	VS1_VC1	VS1_VC2	VS1_VC3	VS1_VC4	VS1_VC5	VS2_VC1	VS2_VC2	VS2_VC3	VS2_VC4	VS2_VC5
Sandia Ref. model	RM1	RM1	RM1	RM1	RM1	RM3	RM3	RM3	RM3	RM3
Complexity	3	3	2	1	1	3	3	2	1	1
No. devices	1	10	1	1	10	1	10	1	1	10
OEC type	fixed TEC	fixed TEC	fixed TEC	fixed TEC	fixed TEC	Floating WEC	Floating WEC	Floating WEC	Floating WEC	Floating WEC

As shown in Table 3.50, a range of verification cases was defined with different device types, number of devices, and defined project parameters aligning with the US DoE 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 tests 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 ten verification cases, five for RM1 test cases and five for RM3, was listed in Table 3.52 and Table 3.55, respectively.

In order to run the LMO module, the RM1 device had to be broken down into the relevant subsystems (pile and device), which will ultimately require specific installation operations. It was assumed that the "device" was comprised of: i) the cross-arm and ii) the two nacelles. It was assumed that the device would be transported and installed as a whole on top of the pile.

For transporting the devices, the device dimensions presented in Table 3.51 and illustrated Figure 3.4 were considered. It was assumed that the device would be transported on the deck of a vessel or barge.

TABLE 3.51: SUMMARY OF INPUTS FROM MC FOR RM1

Length	Width	Height	Mass	Draft
28 m	8.3 m	20 m	37,200 kg	20 m

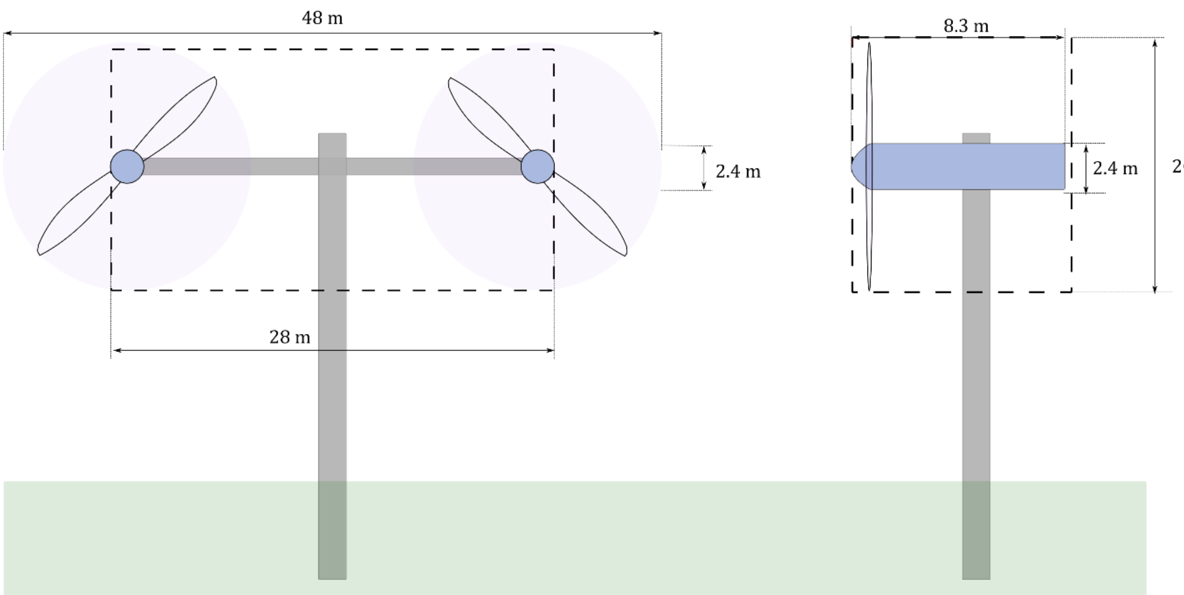


FIGURE 3.4: REPRESENTATION OF THE RM1 DEVICE DIMENSIONS FOR TRANSPORTATION PURPOSES

In respect to maintenance, it is assumed that in case of device failure, the device (both nacelles and cross arm) is retrieved to port and serviced, and then redeployed after the maintenance activity has been completed. Component failures are generated by the RAMS module based on the specified failure rates.

TABLE 3.52: LIST OF VERIFICATION CASES OF THE LOGISTICS AND MARINE OPERATIONS MODULE RELATED TO RM1

Test number	VS1_VC1	VS1_VC2	VS1_VC3	VS1_VC4	VS1_VC5
Sandia Reference model	RM1	RM1	RM1	RM1	RM1
Tool complexity level	3	3	2	1	1
Number of devices	1	10	1	1	10
Ocean energy converter type	fixed TEC	fixed TEC	fixed TEC	fixed TEC	fixed TEC
Installation start date	01/05/2020	01/01/2020	01/01/2020	May-20	May-20
Maintenance start date	01/05/2021	01/05/2021	01/05/2021	May-20	May-20
Project lifetime	20	20	20	20	20
Consider repair at port	TRUE	TRUE	TRUE	TRUE	TRUE
Device fully submerged	TRUE	TRUE	TRUE	TRUE	TRUE
Tow draft (m)	Not defined	Not defined	Not defined	Not defined	Not defined
Maximum wave height Hs(m)	Not defined	Not defined	1.5	1.5	1.5
Weather Window Statistics	Median (p50)	Median (p50)	Median (p50)	Median (p50)	Median (p50)
Vessel statistics	Median (p50)	Median (p50)	Median (p50)	Median (p50)	Median (p50)
MDO price (€/ton)	515			Not defined	Not defined
Specific Fuel Oil Consumption	210			Not defined	Not defined
Load factor	0.8			Not defined	Not defined
Site Characterisation file	6_SC_inputs1.json				
Machine Characterisation file	1_MC_inputs1_1				
Energy Capture file	2_EC_inputs1_1	2_EC_inputs1_2	2_EC_inputs1_1		2_EC_inputs1_2
Energy transformation file	3_ET_inputs1_1	3_ET_inputs1_2	3_ET_inputs1_3	3_ET_inputs1_4	3_ET_inputs1_4
Energy Delivery file	4_ED_inputs1_1	4_ED_inputs1_2	4_ED_inputs1_3	4_ED_inputs1_4	4_ED_inputs1_5
Station Keeping file	5_SK_inputs1_1	5_SK_inputs1_2	5_SK_inputs1_3	5_SK_inputs1_4	5_SK_inputs1_5
Simulate installation	TRUE	TRUE	TRUE	TRUE	TRUE
Simulate maintenance	TRUE	TRUE	TRUE	TRUE	TRUE
Simulate decommissioning	FALSE	FALSE	FALSE	FALSE	FALSE
ROV/Divers	ROVs	ROVs	ROVs	N.D.	N.D.
Filter terminals by:					
Past experience in MRE projects	FALSE	FALSE	Not defined	Not defined	Not defined
Drydock capabilities	FALSE	FALSE	Not defined	Not defined	Not defined
Slipway capabilities	FALSE	FALSE	Not defined	Not defined	Not defined
Available terminal area	FALSE	FALSE	Not defined	Not defined	Not defined
Available crane capabilities	FALSE	FALSE	Not defined	Not defined	Not defined
Quay load bearing capabilities	FALSE	FALSE	Not defined	Not defined	Not defined
Max distance to site	1000 km	1000 km	Not defined	Not defined	Not defined
Operation methods:					
Devices					
Device transportation method	Dry	Dry	Dry	Not defined	Not defined
Device load-out method	lift-away	lift-away	Not defined	Not defined	Not defined

Foundations					
Pile transportation method	dry	dry	Not defined	Not defined	Not defined
Pile loadout method	lift-away	lift-away	Not defined	Not defined	Not defined
Pile installation method	Vibro	Vibro	Not defined	Not defined	Not defined
Anchors					
Anchors loadout method	Not defined	Not defined	Not defined	Not defined	Not defined
Collection points					
Load-out method	Not defined	Not defined	Not defined	Not defined	Not defined
Transportation method	Not defined	Not defined	Not defined	Not defined	Not defined
Cables					
Cable burial method	Ploughing	Ploughing	Not defined	Not defined	Not defined
Cable landfall method	OCT	OCT	Not defined	Not defined	Not defined

To run the LMO module, inputs related to the RM3 device were also compiled. It was assumed that the device would be wet-towed to site. In case of PTO failure, it was considered that the device is towed to site for repair. Rough estimates of the bollard pull requirements were generated based on device geometry, as described in Deliverable D5.7 [13]. For transporting the devices, the device dimensions presented in Table 3.53 were considered.

TABLE 3.53: SUMMARY OF INPUTS FROM MC FOR RM3

Length	Width	Height	Mass	Draft
30 m	30 m	42 m	680,000 kg	35 m

TABLE 3.54: TOW DRAFT OF RM3 FOR THE TOWING OPERATION (CPX3)

Tow draft
15 m

TABLE 3.55: LIST OF VERIFICATION CASES OF THE LOGISTICS AND MARINE OPERATIONS MODULE RELATED TO RM3

Test number	VS2_VC1	VS2_VC2	VS2_VC3	VS2_VC4	VS2_VC5
Sandia Reference model	RM3	RM3	RM3	RM3	RM3
Complexity	3	3	2	1	1
Number of devices	1	10	1	1	10
Ocean energy converter type	Floating WEC	Floating WEC	Floating WEC	Floating WEC	Floating WEC
Installation start date	01/05/2020	01/01/2020	01/01/2020	May-20	May-20
Maintenance start date	01/05/2021	01/05/2021	01/05/2021	May-20	May-20
Project lifetime	20	20	20	20	20
Consider repair at port	TRUE	TRUE	TRUE	TRUE	TRUE
Device fully submerged	FALSE	FALSE	FALSE	FALSE	FALSE
Tow draft (m)	15	15	15	Not defined	Not defined
Maximum wave height Hs (m)	Not defined	Not defined	Not defined	1.5	1.5
Safety factor for vessel selection	0.1	0.1	0.1	Not defined	Not defined

MDO price (€/ton)	515			Not defined	Not defined
Specific Fuel Oil Consumption	210			Not defined	Not defined
Load factor	0.8			Not defined	Not defined
Weather Window Statistics	Median (p50)	Median (p50)	Median (p50)	Median (p50)	Median (p50)
Vessel statistics	Median (p50)	Median (p50)	Median (p50)	Median (p50)	Median (p50)
Site Characterisation file	6_SC_inputs2.json				
Machine Characterisation file	1_MC_inputs2_1				
Energy Capture file	2_EC_inputs2_1	2_EC_inputs2_2	2_EC_inputs2_3	2_EC_inputs2_4	2_EC_inputs2_4
Energy transformation file	3_ET_inputs2_1	3_ET_inputs2_2	3_ET_inputs2_3	3_ET_inputs2_4	3_ET_inputs2_4
Energy Delivery file	4_ED_inputs2_1	4_ED_inputs2_2	4_ED_inputs2_3	4_ED_inputs2_4	4_ED_inputs2_5
Station Keeping file	5_SK_inputs2_1	5_SK_inputs2_2	5_SK_inputs2_3	5_SK_inputs2_4	5_SK_inputs2_5
Simulate installation	TRUE	TRUE	TRUE	TRUE	TRUE
Simulate maintenance	TRUE	TRUE	TRUE	TRUE	TRUE
Simulate decommissioning	FALSE	FALSE	FALSE	FALSE	FALSE
ROV/Divers	ROVs	ROVs	ROVs	Not defined	Not defined
Filter terminals by:					
Past experience in MRE projects	FALSE	FALSE	Not defined	Not defined	Not defined
Drydock capabilities	FALSE	FALSE	Not defined	Not defined	Not defined
Slipway capabilities	FALSE	FALSE	Not defined	Not defined	Not defined
Available terminal area	FALSE	FALSE	Not defined	Not defined	Not defined
Available crane capabilities	FALSE	FALSE	Not defined	Not defined	Not defined
Quay load bearing capabilities	FALSE	FALSE	Not defined	Not defined	Not defined
Max distance to site	1000 km	1000 km	Not defined	Not defined	Not defined
Operation methods:					
Devices					
Device transportation method	Wet	Wet	Wet	Not defined	Not defined
Device load-out method	lift-away	lift-away	Not defined	Not defined	Not defined
Foundations					
Pile transportation method	Not defined	Not defined	Not defined	Not defined	Not defined
Pile loadout method	Not defined	Not defined	Not defined	Not defined	Not defined
Pile installation method	Not defined	Not defined	Not defined	Not defined	Not defined
Anchors					
Anchors loadout method	lift-away	lift-away	Not defined	Not defined	Not defined
Collection points					
Load-out method	N.D.	N.D.	N.D.	N.D.	N.D.
Transportation method	N.D.	N.D.	N.D.	N.D.	N.D.
Cables					
Cable burial method	Ploughing	Ploughing	Not defined	Not defined	Not defined
Cable landfall method	HDD	HDD	Not defined	Not defined	Not defined

3.7.4 Collection of data required

Running the verification cases in the Logistics and Marine Operations module requires a set of input data, which were mostly collated from the Sandia reports, and in some cases, synthesised data sets were produced where real data was not available.

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

- Project inputs: inputs related to the device and project characteristics (see Table 3.56)
- Site inputs: input data related to the site, including lease area coordinates, bathymetry, and met-ocean timeseries, as produced by Site Characterisation (see Table 3.57).
- External inputs: inputs produced from other modules, namely Machine Characterisation, Energy Capture, Energy Transformation, Energy Delivery and Station Keeping (see
- Table 3.58).
- Phase requirements: optional inputs that include user preferences related to infrastructure selection (see Table 3.60).
- Operation methods: optional inputs related to the operational methods to be considered for transporting and loading out devices and subsystems and pile installation methods (see Table 3.59).
- Catalogue data: databases of port terminals, equipment, vessels and operations (see Table 3.61)

TABLE 3.56: PROJECT INPUTS TABLE

Project inputs	Default	Data origin	Units
Project start date	Required	User	Dd/mm/yyyy
Maintenance start date[3]	Com. date	User	Dd/mm/yyyy
Project lifetime	Required	User	years
Consider repair at port	False	User	Bool
Device is fully submerged	False	User	Bool
Device towing draft	Optional	User	m
Marine Diesel Oil (MDO) Fuel price	515	User	€/ton
Specific Fuel Oil Consumption	210	User	g/kWh
Average vessel load factor	0.8	User	-
Weather window statistics	Median (P50)	User	-
Vessel cluster dimension statistics	Median (P50)	User	-
Safety factor for vessel selection	20%	User	%

TABLE 3.57: SITE INPUTS TABLE

Site inputs	Default	Data origin	Units
Site Characterisation input file			
Met-ocean timeseries	Required	SC	–
Site bathymetry	Required	SC	–
Seabed characteristics	Required	SC	–

[3] The current version of LMO requests the maintenance start date from the user. However, in a next version, the commissioning date will be considered as default (if the installation is considered for the analysis).

TABLE 3.58: EXTERNAL INPUTS TABLE

External inputs	Default	Data origin	Units
Machine Characterisation input file			
Device type	Required	MC	WEC/TEC
Device topology	Required	MC	Floating/Fixed
Device dimensions	Required	MC	[m,m,m]
Device towing draft	Optional	User	m
Device mass	Required	MC	kg
Energy Capture input file			
Number of devices	Required	EC	–
Farm layout	Required	EC	–
Energy Transformation input file			
Hierarchy:	**Required**	**ET**	**-**
Mass PTO_elect	Required	ET	Kg
Mass PTO_mech	Required	ET	Kg
Mass PTO_grid	Required	ET	Kg
Total mass PTO	Required	ET	Kg
PTO costs elect	Required	ET	€
PTO costs mech	Required	ET	€
Total PTO costs	Required	ET	€
Rated power	Required	ET	kW
PTO failure rates	Required	ET	1/year
Station Keeping input file			
SK hierarchy file	**Required**	**SK**	**-**
Anchor types	Required	SK	-
Number of anchors per device	Required	SK	-
Anchor height	Required	SK	m
Anchor width	Required	SK	m
Anchor length	Required	SK	m
Anchor mass	Required	SK	Kg
Anchor soil type	Required	SK	-
Anchor cost	Required	SK	€
Mooring length	Required	SK	m
Mooring mass	Required	SK	Kg
Mooring diameter	Required	SK	m
Mooring line cost	Required	SK	€
Foundation type	Required	SK	-
Foundation height	Required	SK	Kg
Foundation diameter	Required	SK	Kg
Foundation length	Required	SK	€
Foundation mass	Required	SK	€
Foundation burial	Required	SK	€
Component failure rates	Required	SK	1/year
Energy Delivery input file			
ED Hierarchy	Required	ED	-
collection Point catalogue ID	Required	ED	-
collection Point location	Required	ED	-
collection Point type	Required	ED	-
collection Point costs	Required	ED	€

cable ID	Required	ED	-
cable route	Required	ED	-
cable length	-	ED	m
cable burial depth	-	ED	m
cable soil type	Required	ED	-
cable type	Required	ED	-
route split pipe	Required	ED	-
route cable protection mattress	Required	ED	-
connector position	Required	ED	-
connector type	Required	ED	-
connector cost	Required	ED	€
connector catalogue ID	Required	ED	-
umbilical position	Required	ED	.
umbilical costs	Required	ED	€
umbilical catalogue ID	Required	ED	-
Component failure rates	Required	ED	1/year

TABLE 3.59: OPERATION METHODS INPUTS TABLE

Operation methods	Default	Data origin	Units
Device transportation method	Dry	User	-
Device load-out method	Lift-away	User	-
Pile transportation method	Dry	User	-
Pile load-out method	Lift-away	User	-
Anchors load-out method	Lift-away	User	-
Collection point transportation method	Dry	User	-
Collection point load-out method	Lift-away	User	-
Cable burial method	Required	User/ED	-
Cable landfall method	OCT	User	

TABLE 3.60: PHASE REQUIREMENTS TABLE

Filter port terminals according to:			
Past experience in marine energy	False	User	-
Sufficient terminal area	False	User	-
Available onshore crane capabilities	False	User	-
Quay soil load bearing capacity	False	User	-
Max port distance to site	1,000	User	km

TABLE 3.61: CATALOGUE TABLE

Operation methods	Data origin	Units
Port terminals	Catalogue	-
Vessel: Vessel combinations	Catalogue	-
Vessel: Vessel clusters	Catalogue	-
Equipment: Cable burial	Catalogue	-
Equipment: Piling	Catalogue	-
Equipment: ROVs	Catalogue	-
Equipment: Divers	Catalogue	-
Operations (Installation, Maintenance, Decommissioning)	Catalogue	-

4. ANALYSIS OF RESULTS

4.1 RUNNING THE VERIFICATION CASES: Site Characterisation (SC)

4.1.1 Quantitative assessment

A total of 7 organisations completed the verification process for different features of the SC tool (EDP, IDOM, NOVA, BV, SABELLA, AAU and EGP) and provided feedback. Figure 4.1 shows the average scores across the four categories of evaluation, highlighting an overall satisfaction with the tool, with all average scores in the range of 3-5.

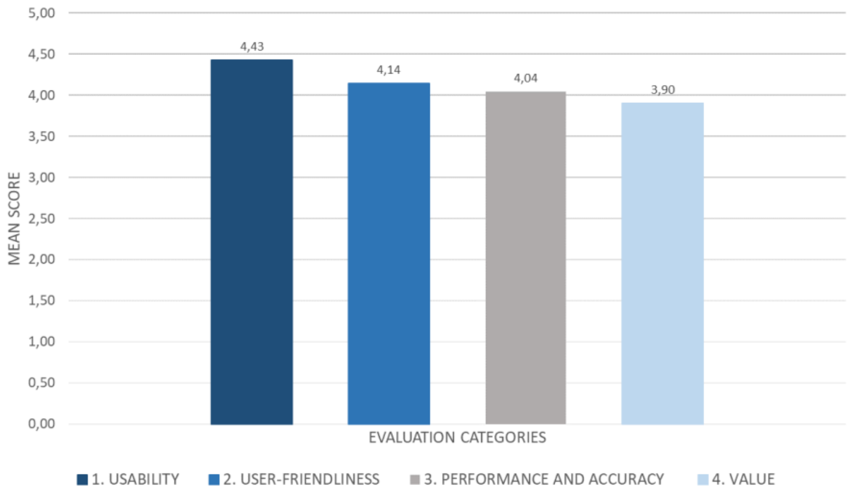


FIGURE 4.1: MEAN RATINGS OF THE EVALUATED CHARACTERISTICS - SC

As shown in Figure 4.2, most of the verification participants (85%) were satisfied with the usability of the SC tool. The majority of (75%) the respondents agree or strongly agree that the tool is generally user friendly. Around 70% (on average) of the respondents agree that the tool shows performance and accuracy. Around 70% of the users considered that the tool is valuable, while 12.5% disagree. Further analysis on the results is described in the following sections.

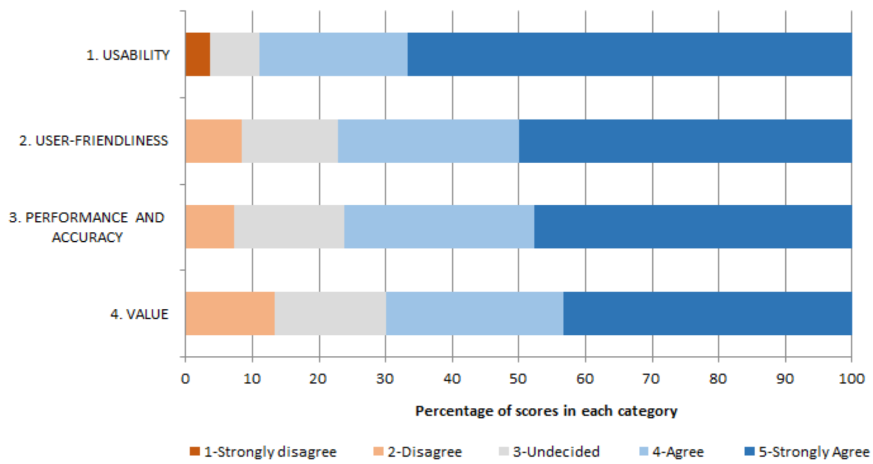


FIGURE 4.2: PERCENTAGE OF SCORES FOR THE FOUR KEY CATEGORIES - SC

4.1.1.1 Usability

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

TABLE 4.1: ASSESSED USABILITY CRITERIA - SC

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.

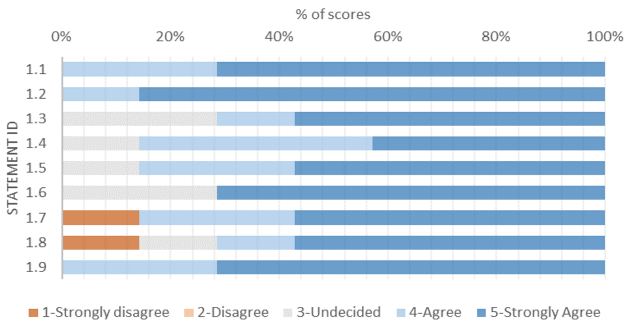


FIGURE 4.3: DISTRIBUTION OF USER SCORES PER USABILITY STATEMENT - SC

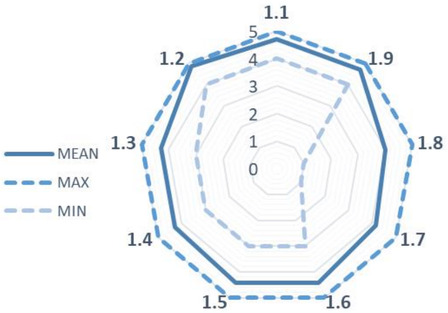


FIGURE 4.4: MEAN, MAXIMUM AND MINIMUM SCORES PER USABILITY STATEMENT - SC

As shown in Figure 4.3, the users unanimously agree that the tool is easy to use and intuitive (ID-1.1), and is easy to create and delete a study (ID-1.2). More than 70% found the process of editing, saving and exporting a study (ID-1.3) straightforward, and over 85% found the process of inputting data (ID-1.4) clear and efficient, while the remaining is undecided. More than 85% of the users find the results obtained meaningful and easy to interpret and use (ID-1.5), with the rest undecided. Over 70% could run the tool without any problem (ID-1.6) and over 85% of the users are satisfied with the speed of computation (ID-1.7) and were able to run the software without any issue (ID -1.8). It was identified that some organisations had issues with the speed of computation and the running of the tool.

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

4.1.1.2 User Friendliness

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

TABLE 4.2: ASSESSED USER FRIENDLINESS CRITERIA - SC

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.

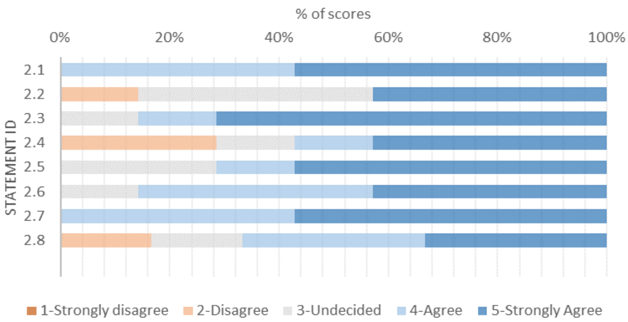


FIGURE 4.5: DISTRIBUTION OF USER SCORES PER USER-FRIENDLINESS STATEMENT - SC

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

As shown in Figure 4.5, all of the respondents agree that the user interface is simple, easy to navigate and well-organised (ID-2.1). However, almost 43% of the users agreed that the user interface looks professional, with the same percentage undecided, and 14% disagree with the statement ID-2.2. Over 85% of the users found that the tool responds promptly to user actions, while the remaining are undecided (ID-2.3). Over 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 is undecided or disagrees. This highlights an improvement area for the next version. The meaning of each data input/user selection and data output is clear for the users, with over 70% of respondents agreeing with statements ID-2.5 and over 85% agreeing with ID-2.6. According to respondents, the visualisation of results is clear and informative, with all respondents agreeing with this statement (ID-2.7). The possibility of adding further information to the study through the interface (ID-2.8) is disputed, with the majority of respondents agreeing with this statement but almost 30% undecided or disagreeing.

The spider diagram in Figure 4.6 shows no significant difference between the maximum and minimum scores, apart from statement ID-2.4 and ID-2.8.

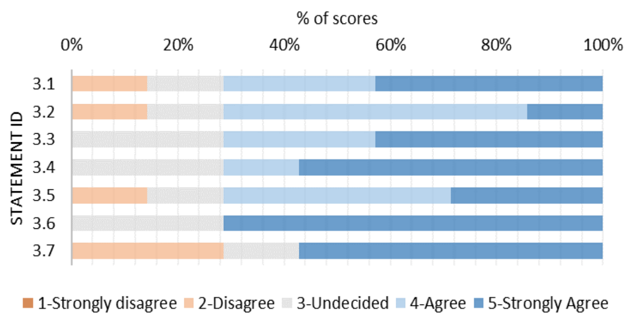
4.1.1.3 Performance and Accuracy

Before the quantitative analysis, it is important to state that the presented results are the outcome of testing two features of the tool. The statements presented in Table 4.3 were assessed regarding the *Performance and Accuracy* of the tool.

TABLE 4.3: ASSESSED PERFORMANCE AND ACCURACY CRITERIA - SC

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.



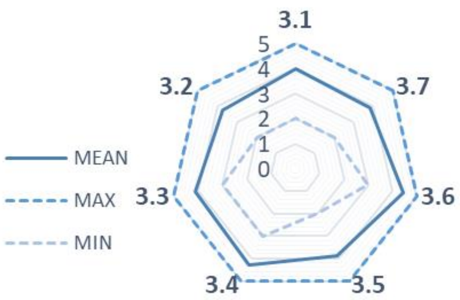


FIGURE 4.7: DISTRIBUTION OF USER SCORES PER PERFORMANCE AND ACCURACY STATEMENT - SC

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

Figure 4.7 shows that around 70% of the testers consider that: the results are robust and not sensitive to small changes of inputs (ID-3.1); 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). 57% agreed that the software can handle errors without crashing (ID-3.7), with almost 30% disagreeing with this statement, highlighting some issues with running the tool.

From the spider graph (Figure 4.8), the mean, maximum and minimum scores are balanced regarding the performance and accuracy of this tool, except for statement ID-3.1, ID-3.2 and ID-3.5.

4.1.1.4 Value

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

TABLE 4.4: ASSESSED VALUE CRITERIA - SC

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.

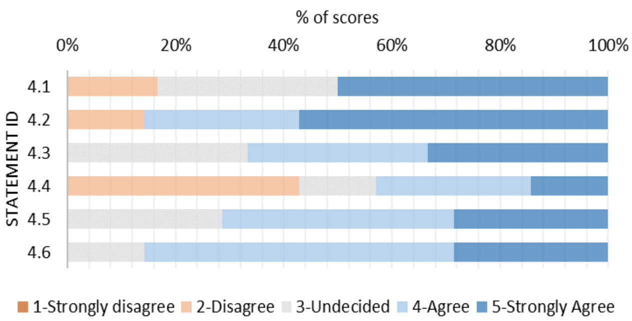


FIGURE 4.9: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT - SC

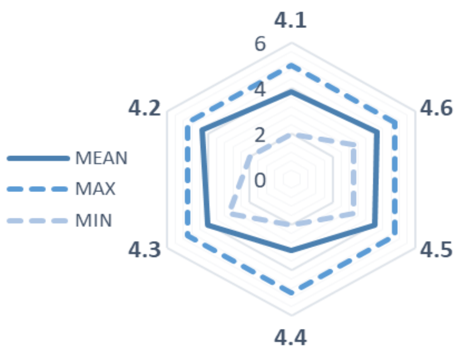


FIGURE 4.10: MEAN, MAXIMUM AND MINIMUM SCORES PER VALUE STATEMENT - SC

Analysing Figure 4.9 highlights that around half the users consider that the software allows the user to fully control the design process (ID-4.1). Over 80% agree that the tool produces results that allow easy comparisons (ID-4.2). For the range of alternatives to create/assess technologies, around 60% of the users agree that the tool provides a large range (ID-4.3). Around 40% of the users agree that the tool provides information about the internal processing (e.g. remaining time, log), with almost half disagreeing (ID-4.4). Around 70% of the respondents agree that the software meets their expectations in terms of results, graphical options, interaction and functionality, while the rest are undecided (ID-4.5). More than 85% of the users would recommend the use of this tool (ID-4.6).

Figure 4.10 shows 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.

4.1.2 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 Site Characterisation (SC) module.

4.1.2.1 Overall user satisfaction

Generally, the feedback indicated that the Site Characterisation (SC) 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 creation of a study and the process of inputting the data is clear and easy to use. Despite the relatively long calculation process (about 5 minutes on average), the results are meaningful and easy to interpret and use. The software does not have a problem to run except for some errors, which are more likely caused by the lack of resource allocated to the server.
- The module is user-friendly as its interface is simple to navigate and well-organised while its look needs little improvement to become more professional. Despite the needs for additional information, all input and output data is comprehensive enough, and the visualisation of the results is clear and informative.
- In terms of performance and accuracy, the results are robust, credible and meet the user expectations. However, the software needs improvement to handle errors more efficiently.

Despite that the module needs to add information about the calculation status (because of the long calculations), the users have recommended the module.

4.1.2.2 Unintended module performance

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

- Some users encountered problems to run the module, which run indefinitely. It happens to be caused by a lack of resource also encountered in other modules.
- Problems were detected with a resolution of buttons that seem to overlap. This occurred when zooming in on the browser used. The module is coded for two sizes of screen, and it will be improved to take into account every possibility.

4.1.2.3 Proposals for improvement

GENERAL REMARKS

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

- The feature to export the results to a PDF needs an improvement as it does not include 2DMaps.
- A particular result in a Verification Case was founded unrealistic, and checks are recommended.

USABILITY

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

- The feature to export to a PDF the results cause problems to one user who got the following message: 'This project was not run yet'. The feature needs to be improve as it should work properly.
- When no complexity level is provided, it is still possible to run the module. The computation is launched and cannot be stopped, and the study cannot be deleted.
- Return periods could be found for waves but not for currents, which are necessary data to design turbines. Making this available to the user is mandatory.

USER-FRIENDLINESS

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

- Key to all abbreviations/acronyms and/or direct links to a glossary or appropriate user manual page for calculations reference should be included in the Graphical User Interface.
- In the Waves and the Current pages, the array's variables should be clearly stated to the user as some of them may not be things usually used by all the users.
- A reference, the site name, or description indicating the site studied on the Overview page could be great.
- The user is not allowed to **provide their own site** at the moment. This feature needs to be included in the module.
- Add information and/or help buttons to help the user understand the module's inputs and outputs.
- Add units of all displayed variables.
- The resolution of a screen or a zoom on the browser usedcould impact the displaying of the Graphical User Interface and needs to be improved.
- Include more information about the used inputs.
- Improvement of the export to PDF feature by adding more information.

PERFORMANCE AND ACCURACY

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

- Include a check of the input consistency.
- Lack of information about the input data utilised when running the module.

VALUE

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

- More information about the calculation time remaining needs to be included.

4.1.3 Identifying and solving inconsistencies

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

Issue	Resolution
Include all abbreviations/acronyms, and/or direct links to a glossary or appropriate page of the user manual for calculations reference.	This will be implemented
In the Waves and the Current pages, the array's variables should be clearly stated to the user because Cge, Spr may not be things usually used by all the users.	This will be implemented
Include a check of the input consistency.	This will be implemented
Add 2DMaps to the export to PDF feature and improve its robustness.	This functionality will be improved
Add information about the used input data.	Some information will be added such as plot and basic information to make it more understandable
Include the possibility to import its own databases	This will be implemented as soon as possible in the module.
The results of a particular Verification Case seems unrealistic and needs to be checked.	The calculation will be checked
When no Complexity Level is provided, it is still possible to run the module. The	Security will be included to avoid this

computation is launched and cannot be stopped, and the study cannot be deleted.	
The RM1-SC4 scenario values for return periods are available for waves, but not for currents, which are necessary data to design turbines. Making this available to the user is mandatory. The graphs plotted are nice, but the statistical values are not realistic for these tests	This new statistic will be implemented, and a check will be performed on the calculation of this case
Add information and/or help buttons to help the user understand inputs and outputs of the module	This will be implemented

TABLE 4.6: LOW PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF SC

Issue	Resolution
Include information about the remaining time of the calculation	This will be updated to include a progress bar
Adding comparisons between different geographical sites might be considered for future developments of the module.	Implemented if possible
Resolve the problem to run the module and reach the end of the calculation.	This problem was more likely due to a lack of resource allocated in the server. However, this problem will be monitored to see if it persists.
Make the interface more professional	The interface will be improved
Problem with the resolution of the explorer. Somme button are overlapped when the window is zoomed	This will be improved
Mag and Theta should be further defined and could even be presented in a compass-like plot with North, East…	The plot will be modified if it is in accordance with all usage of the module
When only one point is selected for the graphs, the choice made should be specified (for instance, the height chosen for currents, or if it's an average over height etc.). Maybe the author is supposed to know it because the	More information will be implemented

input data is already averaged over height, but it could be specified anyway in the exported file (or at least the input chosen).	
Allow the user to export results under an Excel file in addition to the PDF format, particularly for the MAG-THETA or Hs-Tp/ Hs-Dp plots with discretization steps that would be defined by the user	Will be implemented if possible
Add more information about input on the export PDF	Will be implemented if possible

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

Issue	Resolution and Explanation why it will not be implemented
Reduce the time of the computation	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

4.2 RUNNING THE VERIFICATION CASES: Machine Characterisation (MC)

4.2.1 Quantitative assessment

A total of 6 organisations completed the verification process for the different features of the MC module (NOVA, Sabella, FEM, EGP, EDP, BV) 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 3,5 to 4,5.

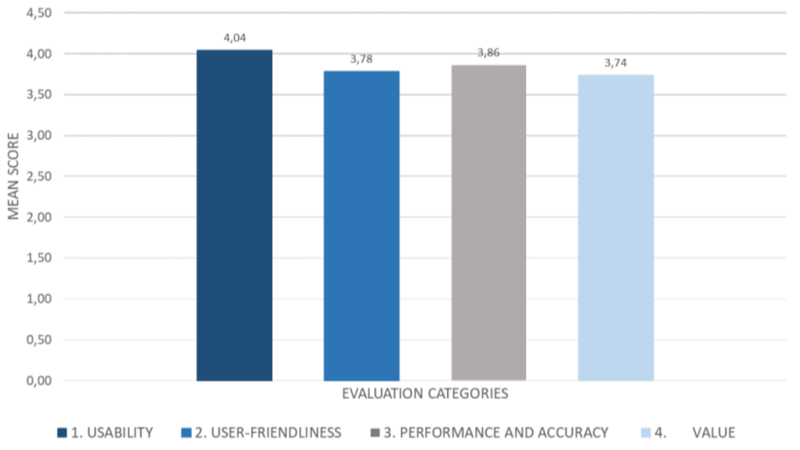


FIGURE 4.11: MEAN RATINGS OF THE EVALUATED CHARACTERISTICS - MC

As shown in Figure 4.12, most of the verification participants (>70%) were satisfied with the usability of the MC tool. The majority of (almost 60%) the respondents agree or strongly agree that the tool is generally user friendly. Around 60% (on average) of the respondents agree that the tool shows performance and accuracy. Around 60% of the users considered that the tool is valuable, while around 20% disagree. Further analysis of the results is described in the following sections.

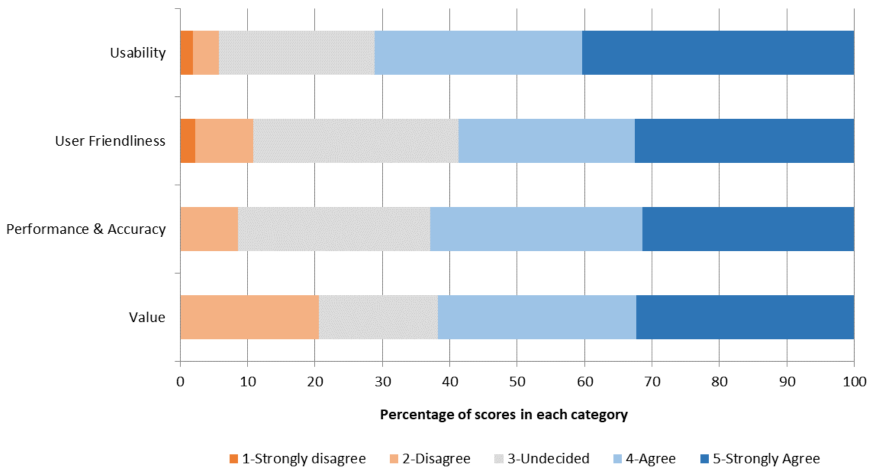


FIGURE 4.12: PERCENTAGE OF SCORES FOR THE FOUR KEY CATEGORIES - MC

4.2.1.1 Usability

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

TABLE 4.8: ASSESSED USABILITY CRITERIA - MC

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.

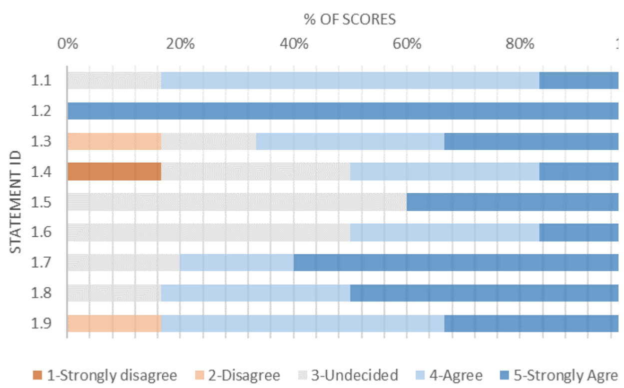


FIGURE 4.13: DISTRIBUTION OF USER SCORES PER USABILITY STATEMENT - MC

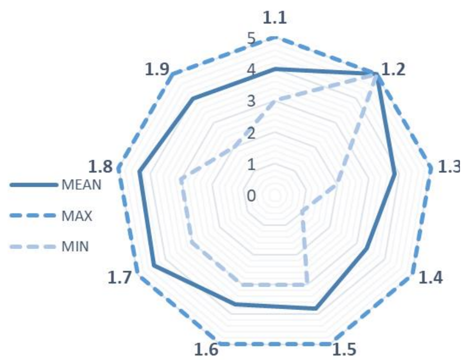


FIGURE 4.14: MEAN, MAXIMUM AND MINIMUM SCORES PER USABILITY STATEMENT - MC

All the users strongly agree that it's easy to create a study and delete it (ID-1.2). Also, around 80% agree or strongly agree that: the tool is easy to use in general (ID-1.1); the overall speed of computation is satisfactory (ID-1.7); the software can be run from their computer without any issue (ID-1.8); the training sessions and documentation are useful for learning how to use the software (ID-1.9). The remaining respondents are undecided for ID-1.1, ID-1.7 and ID-1.8, and disagree on ID-1.9.

Two thirds of the users considered it's easy to edit, save and export a study, while one third disagreed or are undecided (ID-1.3). 50% of the users agree or strongly agree that inputting data is clear and efficient (ID-1.4); could complete the process without errors (ID-1.6). The other half of the respondents are undecided or strongly disagree with ID-1.4 and are undecided for ID-1.6. About the ID-1.5 "the results are meaningful, easy to interpret and use", 40% of the users strongly agree with it, and the other 60% are undecided on this criterion.

From the spider graph, it's possible to see that all the mean values of the criteria are always placed above 3. One note for the consensus achieved on criterion ID-1.2 – all the users strongly agree with this.

4.2.1.2 User Friendliness

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

TABLE 4.9: ASSESSED USER FRIENDLINESS CRITERIA - MC

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.

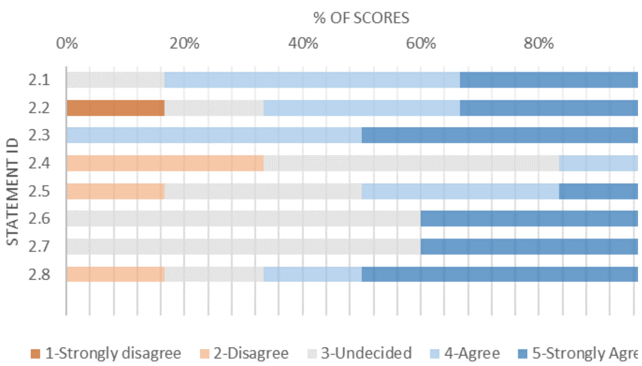


FIGURE 4.15: DISTRIBUTION OF USER SCORES PER USER-FRIENDLINESS STATEMENT - MC

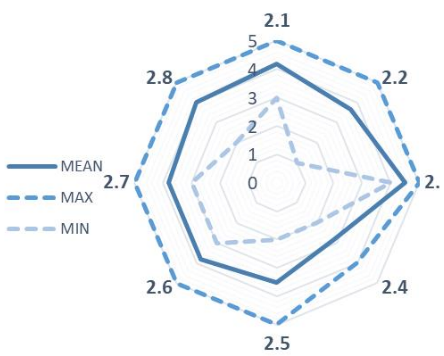


FIGURE 4.16: MEAN, MAXIMUM AND MINIMUM SCORES PER USER-FRIENDLINESS STATEMENT - MC

All the users strongly agree or agree that the tool responds promptly to user actions (inputs, selections, clicks, ...) (ID-2.3). Two thirds of the respondents considered 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). In contrast, the remaining ones are undecided or strongly disagree for criterion ID-2.2 and are undecided or disagree for criterion ID-2.8. More than 80% of the users agree or strongly agree that the user interface is simple, easy to navigate and well-organised (ID-2.1). The others were undecided.

About ID-2.6 and ID-2.7, 40% of the users considered that each data output's meaning is clear, and the visualisation of results is clear and informative, while the other 60% were undecided. Half of the users agree or strongly agree that the meaning of each data input/user selection is clear (ID-2.5) and the other half is undecided or disagree. Just 17% of the respondents considered that the tool provides enough help, indications and/or guidance thro ughout each process (ID-2.4), while the majority is undecided or disagree on this.

From the spider graph, it's possible to gauge that the average classification in all the criteria was satisfactory despite the low minimum value registered on criterion ID-2.2.

4.2.1.3 Performance and Accuracy

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

TABLE 4.10: ASSESSED PERFORMANCE AND ACCURACY CRITERIA - MC

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.

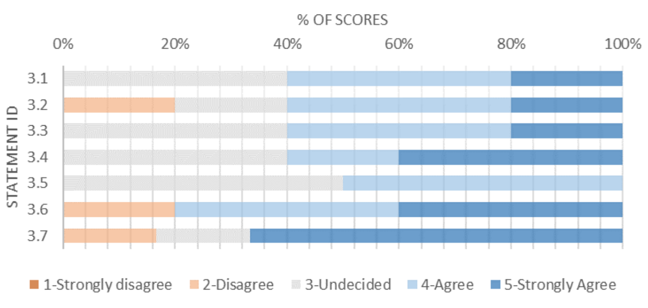


FIGURE 4.17: DISTRIBUTION OF USER SCORES PER PERFORMANCE AND ACCURACY STATEMENT - MC

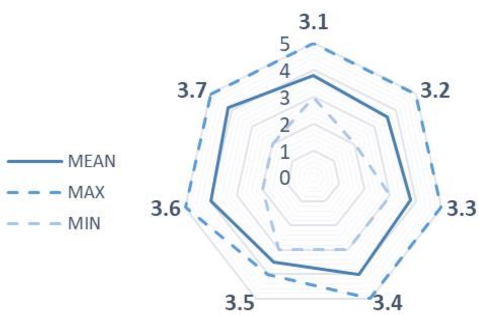


FIGURE 4.18: MEAN, MAXIMUM AND MINIMUM SCORES PER PERFORMANCE AND ACCURACY STATEMENT - MC

About 60% of the user considered that: Results are robust and not sensitive to small changes of inputs (ID-3.1); Results are credible and trustworthy for the audience (ID-3.2); the accuracy of results is acceptable considering the granularity/complexity of data inputs used (ID-3.3); the accuracy of results corresponds to the user expectation for the stage of technology maturity (ID-3.4). The remaining users are undecided for these criteria, with a slight difference in criterion ID-3.2 – 20% of the respondents disagree.

On criterion ID-3.5, half of the users agree that the computational time is adequate for the level of accuracy provided, while the other half was undecided. 80% of the respondents agree or strongly agree that the software did not suffer from any sort of data shortage/lack of memory during the test (ID-3.6) and the other 20% disagree on this. Finally, two thirds of the users strongly agree that the software can handle errors without crashing (ID-3.7), while the rest are undecided or disagree on this.

From the spider chart and considering the mean values, we can state that the results obtained in this criteria assessment were always above 3 – Undecided.

4.2.1.4 Value

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

TABLE 4.11: ASSESSED VALUE CRITERIA - MC

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.

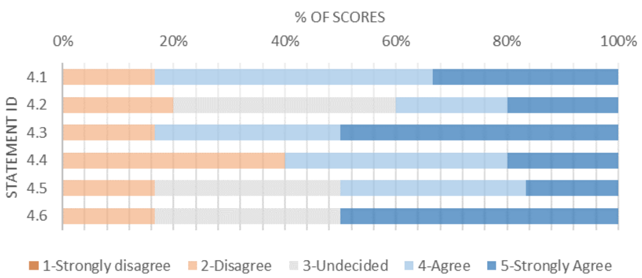


FIGURE 4.19: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT - MC

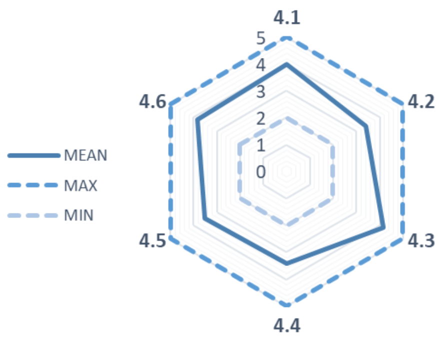


FIGURE 4.20: MEAN, MAXIMUM AND MINIMUM SCORES PER VALUE STATEMENT - MC

Less than 20% disagree on that: the software allows the user full control of the design process (ID-4.1); the tool provides a large range of alternatives to create/assess technologies (ID-4.3); that the software meets the expectations in terms of results, graphical options, interaction, and functionality (ID-4.5); would recommend the use of this software (ID-4.6).

On criterion ID-4.2, 40% of the users agree or strongly agree that the tool produces results that allow easy comparisons, 40% are undecided, and 20% disagree. 60% of the respondents agree or strongly agree that the user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies (ID-4.4), while the remaining 40% disagree on this.

From the spider chart, we can see that the opinions on these criteria were far from consensus. It was registered a minimum value of 2 and a maximum value of 5 in all the criteria. This could be justified with the different expectations of the user regarding the *Value* of the tool.

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 experience*, *Unintended module performance*, and *Proposals for improvement*. The aim of this section is to guide the path for improvement of the Machine Characterisation (MC) module.

4.2.2.1 Overall user satisfaction

Generally, the feedback indicated that the Machine Characterisation (MC) module flow could be improved to facilitate the user process. The users highlighted that the GUI 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, creating a study and the process of inputting the data should be improved; for example, some fields miss the units, and others can be represented graphically to ease the understanding.
- The module is pretty user-friendly as its interface is simple to navigate and well-organized while its look needs little improvement to become more professional. Despite the needs for additional information, all input and output data is comprehensive enough, and the results' visualisation is clear and informative.
- In term of performance and accuracy, the results are robust, credible and meet the user expectations. However, the software needs improvement to handle errors more efficiently.
- For the long calculation case, the user is not informed about the actual status of the calculation; this leads to confusion on whether the process is running or failing.

4.2.2.2 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:

- For the tidal case at a high complexity level, the user could not select the cut in and cut out velocity due to a bug in the code.

There is, although, interference between the Machine Characterisation and the Energy Capture module in the set-up of the background calculation that must be addressed.

4.2.2.3 Proposals for improvement

GENERAL REMARKS

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

- The feature to save the results to the file did not work properly.

In general, the users did not understand that the MC module does not have calculation, apart from the case of wave energy converters at complexity 3. This should be made more explicit in the documentation or training sessions.

USABILITY

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

- The interface misses a proper definition of the variable or/and units. This makes the overall process difficult to complete.

USER-FRIENDLINESS

The user-friendliness follows the comments of the software usability.

- The lack of clear definition and units of the different inputs hinders the interface usability.

PERFORMANCE AND ACCURACY

The MC module only has a calculation for the wave case at complexity 3. For that case, the main comment from the users is:

- The computation time is too long.

VALUE

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

- More information about the remaining calculation time and the validity of the inputs needs to be included.

4.2.3 Identifying and solving inconsistencies

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

Issue	Resolution
Include all abbreviations/acronyms and/or direct links to a glossary or appropriate page of the user manual for calculations reference.	This will be implemented
Clarify the study flow to the user. Calculation or no calculation!	This will be implemented
Include a check of the input consistency.	This will be implemented
Include the study title in the study view	This functionality will be improved
Improve the export and import study functionality	This functionality will be improved
Add information and/or help buttons to help the user understand inputs and outputs of the module	This will be implemented
Cut-in cut-out velocity slider bug	This bug will be fixed
Include more information for the user for the case of wave energy converter at complexity 3	Although complex, the developer will try his best to help the user in the process.
Problem with negative Moment of Inertia	This bug will be fixed
The model page is slow to render	This functionality will be improved
Add coordinate system definition	This will be implemented

TABLE 4.13: LOW PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION MC

Issue	Resolution
Include information about the remaining time of the calculation	This will be updated to include a progress bar

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

Issue	Resolution
Responsive layout	The layout is intended to be seen in full screen.

4.3 RUNNING THE VERIFICATION CASES: Energy Capture (EC)

4.3.1 Quantitative assessment

A total of 7 organisations completed the verification process for different features of the EC tool (EDP, IDOM, NOVA, BV, SABELLA, WAVEC and EGP) and provided feedback. Figure 4.21 shows the average scores across the four categories of evaluation, highlighting an overall strong satisfaction with the tool, with all average scores in the range of 4-5.

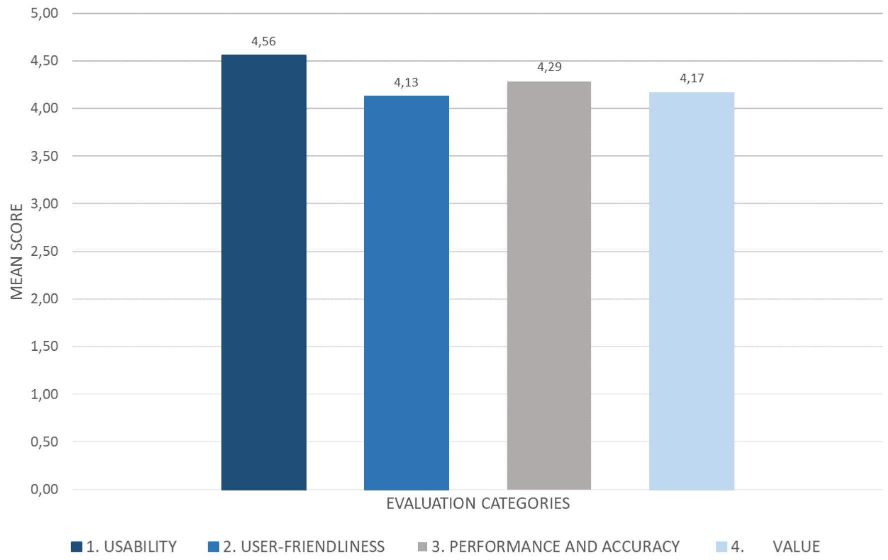


FIGURE 4.21: MEAN RATINGS OF THE EVALUATED CHARACTERISTICS - EC

As shown in Figure 4.22, most of the verification participants (>90%) were satisfied with the EC tool's usability. The majority of (>75%) the respondents agree or strongly agree that the tool is generally user friendly. Almost 90% (on average) of the respondents agree that the tool shows performance and accuracy. The majority of users considered that the tool is valuable, while only just over 2% disagree. Further analysis of the results is described in the following sections.

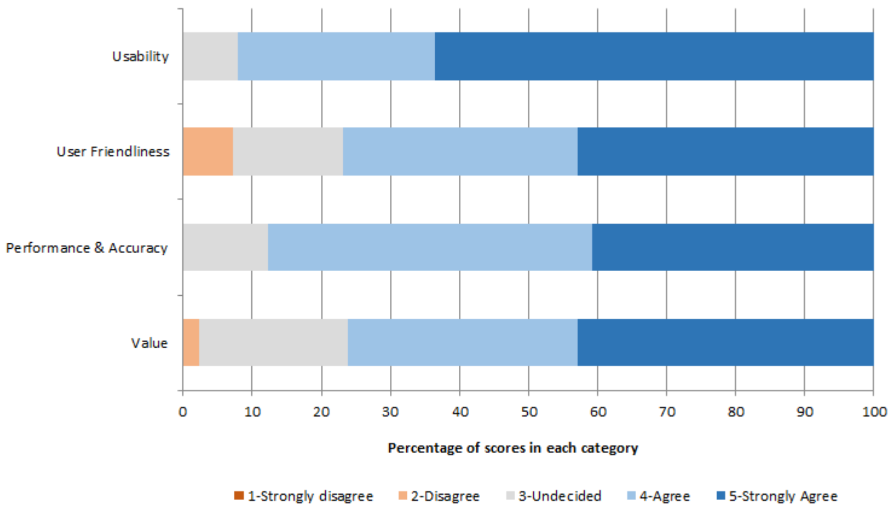


FIGURE 4.22: PERCENTAGE OF SCORES FOR THE FOUR KEY CATEGORIES - EC

4.3.1.1 Usability

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

TABLE 4.15: ASSESSED USABILITY CRITERIA - EC

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 4.23 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.24 using a spider chart, to highlight the mean, maximum and minimum values.

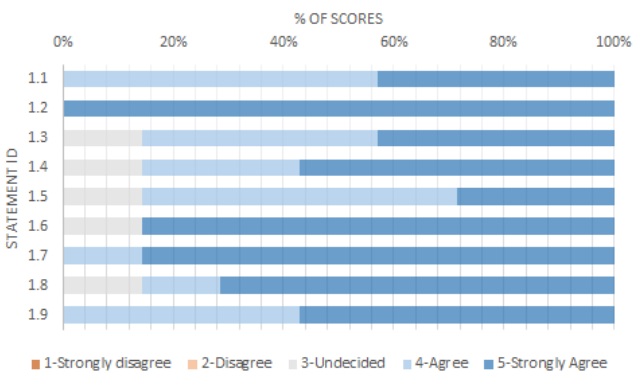


FIGURE 4.23: DISTRIBUTION OF USER SCORES PER USABILITY STATEMENT - EC

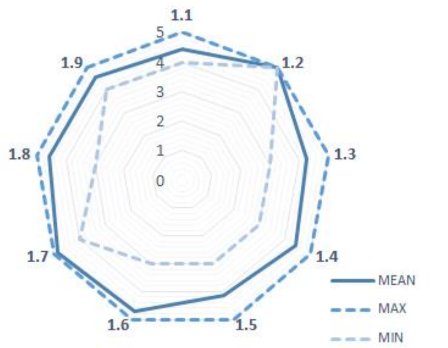


FIGURE 4.24: MEAN, MAXIMUM AND MINIMUM SCORES PER USABILITY STATEMENT - EC

As shown in Figure 4.23, the users unanimously agree that the tool is easy to use and intuitive (ID-1.1) and is easy to create and delete a study (ID-1.2). More than 80% found the process of editing, saving and exporting a study (ID-1.3) straightforward, and found the process of inputting data (ID-1.4) clear and efficient, while the remaining is undecided. The same percentage of the users also find the results obtained meaningful and easy to interpret and use (ID-1.5) and could run the tool without any problem (ID-1.6). All of the users are satisfied with the computation speed (ID-1.7), and more than 80% were able to run the software without any issue (ID -1.8). All of the users find the documentation and the training sessions led by the software developer useful (ID-1.9). As shown in Figure 4.24, all responses gave a high score across all Usability statement.

4.3.1.2 User Friendliness

The following statements have been assessed in the *User friendliness* category.

TABLE 4.16: ASSESSED USER FRIENDLINESS CRITERIA - EC

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 4.25 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.26 using a spider chart to highlight the mean, maximum and minimum values.

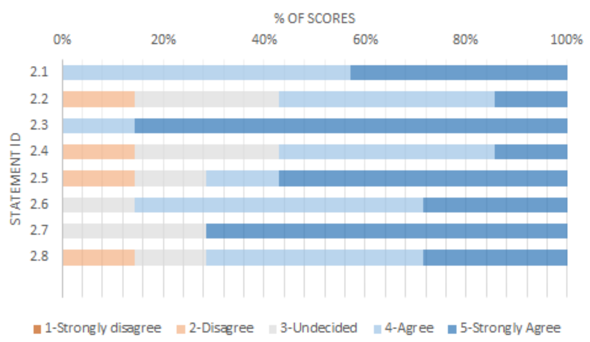


FIGURE 4.25: DISTRIBUTION OF USER SCORES PER USER-FRIENDLINESS STATEMENT - EC

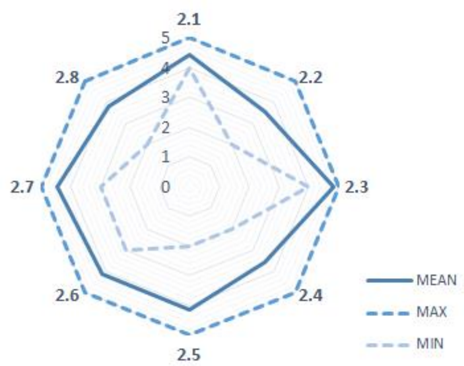


FIGURE 4.26: MEAN, MAXIMUM AND MINIMUM SCORES PER USER-FRIENDLINESS STATEMENT - EC

As shown in Figure 4.25, all the respondents agree that the user interface is simple, easy to navigate and well-organised (ID-2.1). However, 57% of the users agreed that the user interface looks professional, with the rest undecided and 14% disagreeing with the statement (ID-2.2). 100% of the users found that the tool responds promptly to user actions (ID-2.3). Over 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 is undecided or disagrees. This highlights an improvement area for the next version. The meaning of each data input/user selection and data output is clear for the users, with over 70% of respondents agreeing with statements ID-2.5 and over 80% agreeing with ID-2.6. The Visualisation of results is clear and informative according to 71% of respondents who agree with this statement (ID-2.7). The majority of respondents agree that there is a possibility of adding further information to the study through the interface (ID-2.8), but almost 30% are undecided or disagree.

The spider diagram in Figure 4.26 shows no significant difference between the maximum and minimum scores for around half the statements.

4.3.1.3 Performance and Accuracy

The following statements have been assessed in the *Performance and Accuracy* category.

TABLE 4.17: ASSESSED PERFORMANCE AND ACCURACY CRITERIA - EC

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 4.27 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.28 using a spider chart to highlight the mean, maximum and minimum values.

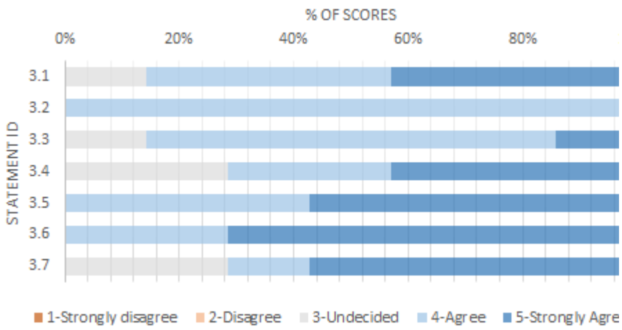


FIGURE 4.27: DISTRIBUTION OF USER SCORES PER PERFORMANCE AND ACCURACY STATEMENT – EC

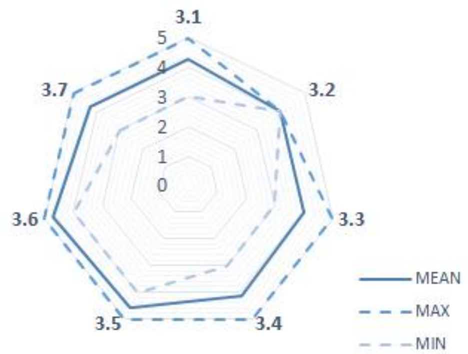


FIGURE 4.28: MEAN, MAXIMUM AND MINIMUM SCORES PER PERFORMANCE AND ACCURACY STATEMENT - EC

Figure 4.27 shows that over 80% of the testers consider 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). All users agreed the results are credible and trustworthy (ID-3.2), with around 70% agreeing the accuracy of the results corresponds to the user expectation for the stage of the technology maturity (ID-3.4). All of the users agreed that 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 (ID-3.6). Around 70% agreed that the software can handle errors without crashing (ID-3.7), with almost 30% undecided with this statement, highlighting some issues with running the tool, which may or not be caused by the module itself.

From the spider graph (Figure 4.28), the mean, maximum and minimum scores are balanced regarding the performance and accuracy of this tool.

4.3.1.4 Value

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

TABLE 4.18: ASSESSED VALUE CRITERIA - EC

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 4.29 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.30 using a spider chart to highlight the mean, maximum and minimum values

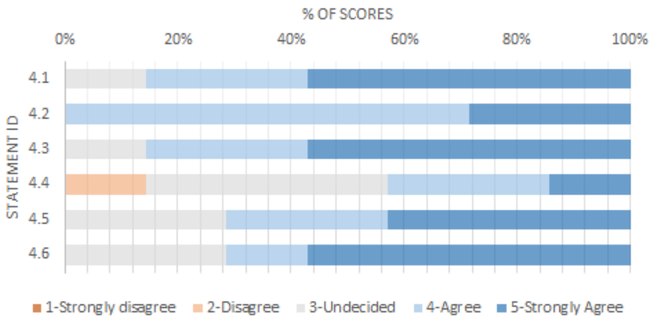


FIGURE 4.29: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT - EC

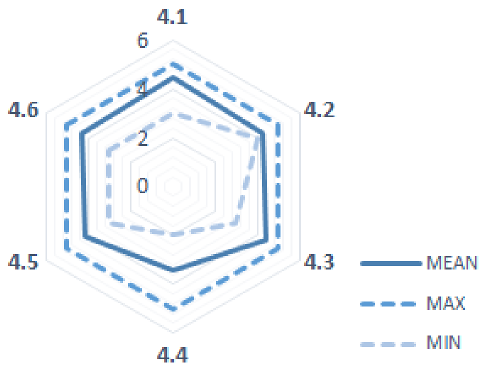


FIGURE 4.30: MEAN, MAXIMUM AND MINIMUM SCORES PER VALUE STATEMENT - EC

Analysing Figure 4.29, over 80% of the users consider that the software allows the user full control of the design process (ID-4.1). 100% agree that the tool produces results that allow easy comparisons (ID-4.2). For the range of alternatives to create/assess technologies, over 80% of the users agree that the tool provides a large range (ID-4.3). Around 40% of the users agree that the tool provides information about the internal processing (e.g. remaining time, log), with over half disagreeing or undecided (ID-4.4). This can be a point of improvement for the next version of the module. Around 70% of the respondents agree that the software meets their expectations in terms of results, graphical options, interaction and functionality, while the rest are undecided (ID-4.5). More than 70% of the users would recommend the use of this tool (ID-4.6).

Figure 4.30 shows differences between the minimum (score – 2) and maximum (score – 5) for statement ID-4.4, which should be explored for future versions.

4.3.2 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 Energy Capture (EC) module.

4.3.2.1 Overall user satisfaction

Generally, the feedback indicated that the Energy Capture (EC) module flow can be improved to facilitate the user process. The users highlighted that the GUI 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 creation of a study and the process of inputting the data should be improved; the variables can be represented graphically to ease the understanding.
- The module is pretty user-friendly as its interface is simple to navigate and well-organized while its look needs little improvement to become more professional. The results are quite comprehensible, but the additional output should be included to improve the user experience.
- The results are robust and meet user expectations.
- The software needs improvement to handle errors more efficiently.
- Once the calculation is launched, the user is not informed about its status, leading to confusion.

4.3.2.2 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:

- The farm layout input is not correctly represented in the table on the reload. Further, using a comma or dot-separated excel value is not correctly caught.
- If the user selects an optimisation strategy and then goes back to the verification case with a specific layout, the system will still perform an optimisation action.
- There is an interaction between the EC and MC long calculation processes that must be solved.

4.3.3 Identifying and solving inconsistencies

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

Issue	Resolution
Include all abbreviations/acronyms and/or direct links to a glossary or appropriate page of the user manual for calculations reference.	This will be implemented
The farm layout table does not render the data correctly and cannot be modified	This will be implemented
Include a check of the input consistency and improve the message error.	This will be implemented
Include feedback on the calculation status	This functionality will be improved
Add the project title to the study page for clarity.	This functionality will be improved
Improve site and machine upload summary view	This functionality will be improved
Use meaningful units and rounded number	This functionality will be improved

TABLE 4.20: LOW PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF EC

Issue	Resolution
Include the orientation angle for each machine	The feasibility of this improvement must be verified first
Change the input files from json to excel	The feasibility of this improvement must be verified first
Improve the help section	The interface will be improved
Make the interface more professional (although this comment is hard to understand)	The interface will be improved

4.3.3.1 Proposals for improvement

GENERAL REMARKS

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

- The system does not consider the Beltz limit for a free stream tidal turbine.
- The study page should report the study title and not only the study ID.

USABILITY

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

- The interface misses a proper definition of the variable or/and units. This makes the overall process difficult to complete.
- The farm layout table has several bugs and must be changed completely.

USER-FRIENDLINESS

The user-friendliness follows the comments of the software usability.

The lack of clear definition and units of the different inputs hinders the interface usability. In addition, the user gave some additional comments:

- The interface misses a proper definition of the variable or/and units. This makes the overall process difficult to complete.
- The farm layout table has several bugs and must be changed completely.
- The machine and site views are updated only at reload
- The variable must be rounded to reasonable digits and avoid to use Billion but mostly MW, KW or GW.
- The error message from the file upload is unreadable.

PERFORMANCE AND ACCURACY

The user comments from performance and accuracy were somehow positive; one user expressed his/her doubt that the q-factor for the tidal machine was not 1. This comment must be further investigated.

VALUE

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

- It could be nice to allow the user to specify each device's orientation angle instead of using a global value.

4.4 RUNNING THE VERIFICATION CASES: Energy Transformation (ET)

4.4.1 Quantitative assessment

A total of 6 organisations completed the verification process for different features of the ET tool (EDP, IDOM, UEDIN, Sabella, EGP, and BV) and provided feedback. Figure 4.31Figure 4.1 shows the average scores across the four categories of evaluation, highlighting an overall satisfaction with the tool, with all average scores in the range of 3-5.

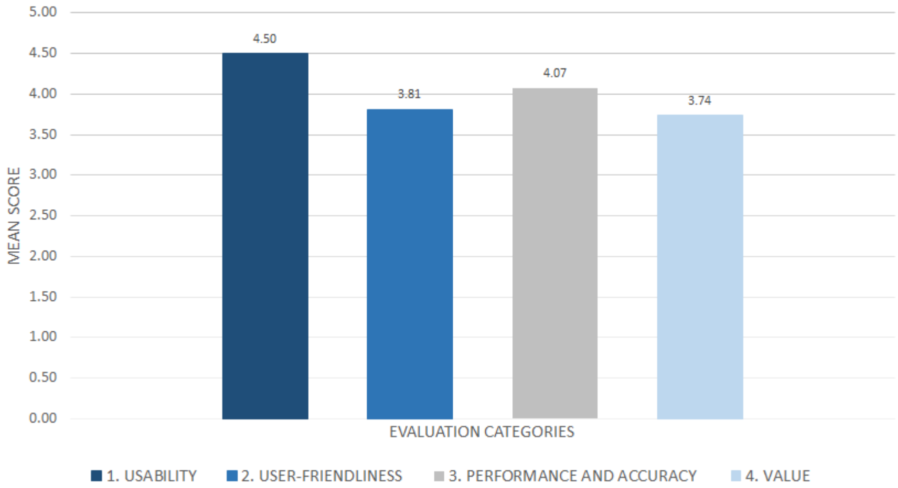


FIGURE 4.31: MEAN RATINGS OF THE EVALUATED CHARACTERISTICS - ET

As shown in Figure 4.32, most of the verification participants (over 90%) were satisfied with the usability of the ET tool. The majority of (almost 70%) the respondents agree or strongly agree that the tool is generally user friendly. Almost 70% (in average) of the respondents agree that the tool shows performance and accuracy. Around 65% of the users considered that the tool is valuable, while almost 20% disagree. Further analysis of the results is described in the following sections.

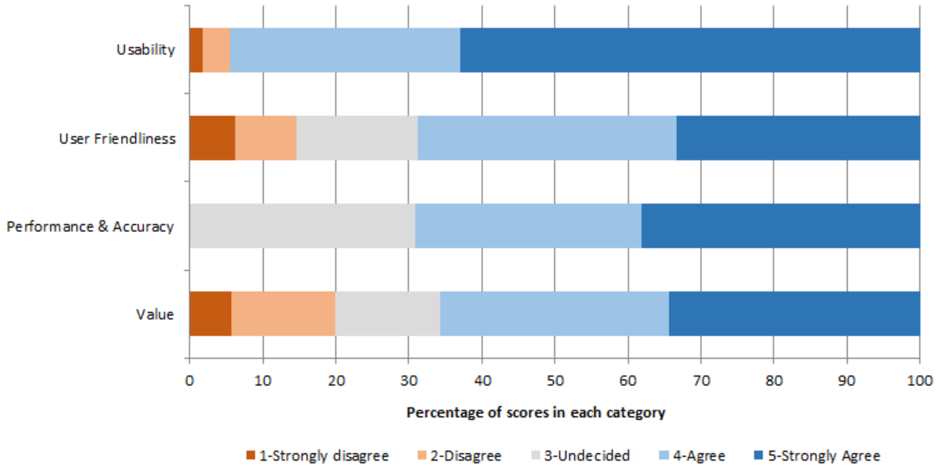


FIGURE 4.32: PERCENTAGE OF SCORES FOR THE FOUR KEY CATEGORIES - ET

4.4.1.1 Usability

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

TABLE 4.21: ASSESSED USABILITY CRITERIA - ET

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 4.34Figure 4.4 using a spider chart to highlight the mean, maximum and minimum values.

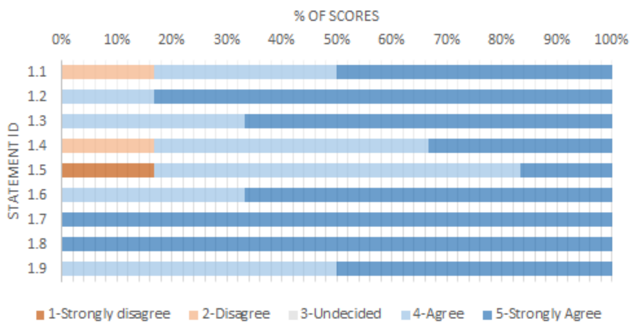


FIGURE 4.33: DISTRIBUTION OF USER SCORES PER USABILITY STATEMENT - ET

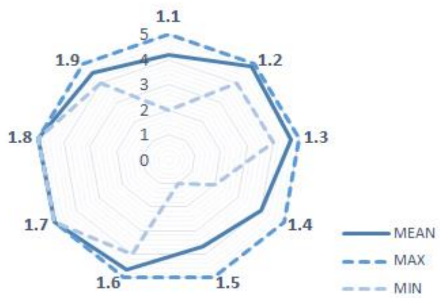


FIGURE 4.34: MEAN, MAXIMUM AND MINIMUM SCORES PER USABILITY STATEMENT - ET

As shown in Figure 4.33, most users (over 80%) agree that the tool is easy to use and intuitive (ID-1.1), with every user agreeing that it is easy to create and delete a study (ID-1.2). All of the users found the process of editing, saving and exporting a study (ID-1.3) straightforward, and over 80% found the process of inputting data (ID-1.4). More than 85% of the users find the results obtained meaningful and easy to interpret and use (ID-1.5), with the rest strongly disagreeing. This is an area to look at for improvement. All of the users could run the tool without any problem (ID-1.6), were satisfied with the speed of computation (ID-1.7) and were able to run the software without any issue (ID -1.8). All of the users find the documentation and the training sessions led by the software developer useful (ID-1.9).

As shown in Figure 4.34, the range of response from users was in general balanced, apart from statement ID1.1, 1.4, and 1.5, which should be addressed in the next version of the tool.

4.4.1.2 User Friendliness

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

TABLE 4.22: ASSESSED USER FRIENDLINESS CRITERIA - ET

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 4.35Figure 4.5 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.36 using a spider chart to highlight the mean, maximum and minimum values.

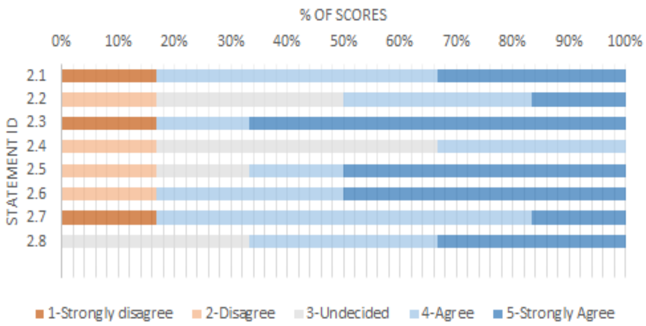


FIGURE 4.35: DISTRIBUTION OF USER SCORES PER USER-FRIENDLINESS STATEMENT - ET

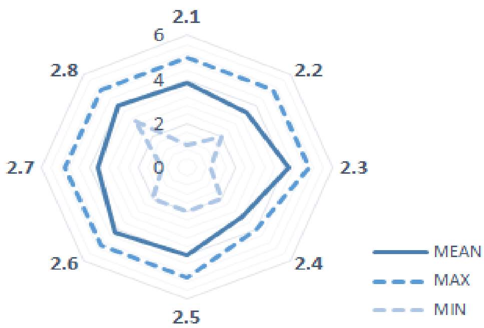


FIGURE 4.36: MEAN, MAXIMUM AND MINIMUM SCORES PER USER-FRIENDLINESS STATEMENT – ET

As shown in Figure 4.35, over 80% of the respondents agree that the user interface is simple, easy to navigate and well-organised (ID-2.1). However, only half of the users agreed that the user interface looks professional, with over 15% disagreeing with the statement ID-2.2. Over 85% of the users found that the tool responds promptly to user actions, while the remaining disagree (ID-2.3). Just over 30% 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 is undecided or disagrees. This highlights an improvement area for the next version. The meaning of each data input/user selection and data output is clear for the users, with over 65% of respondents agreeing with statements ID-2.5 and over 80% agreeing with ID-2.6. According to respondents, the Visualisation of results is clear and informative, with over 80% agreeing with this statement (ID-2.7). The possibility of adding further information to the study through the interface (ID-2.8) is unclear, although the majority of respondents agree with this statement, and almost 30% are undecided.

The spider diagram in Figure 4.36 shows there is sometimes quite a significant difference between the maximum and minimum scores, highlighting the user's expectation of user friendliness.

4.4.1.3 Performance and Accuracy

The presented results are the outcome of the testing of two features of the tool. The statements presented in the following table were assessed regarding the *Performance and Accuracy* of the tool.

TABLE 4.23: ASSESSED PERFORMANCE AND ACCURACY CRITERIA - ET

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.

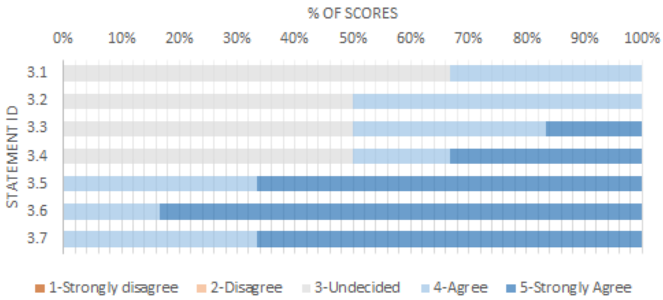


FIGURE 4.37: DISTRIBUTION OF USER SCORES PER PERFORMANCE AND ACCURACY STATEMENT - ET

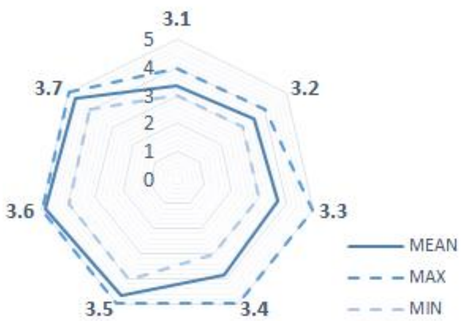


FIGURE 4.38: MEAN, MAXIMUM AND MINIMUM SCORES PER PERFORMANCE AND ACCURACY STATEMENT - ET

Figure 4.37 shows that only just over 30% of the testers consider that: the results are robust and not sensitive to small changes of inputs (ID-3.1); with half agreeing 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 rest are undecided, meaning that probably the resources provided were unavailable or insufficient for the users to be able to verify the quality of the results.

For the following three statements (ID3-5, 3-6, 3-7), all users testing the tool agreed that the computational time is adequate for the level of accuracy provided, 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 (ID-3.7).

From the spider graph (Figure 4.38), the mean, maximum and minimum scores are balanced regarding the performance and accuracy of this tool.

4.4.1.4 Value

The following criteria were assessed regarding the *Value* of the tool.

TABLE 4.24: ASSESSED VALUE CRITERIA - ET

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.

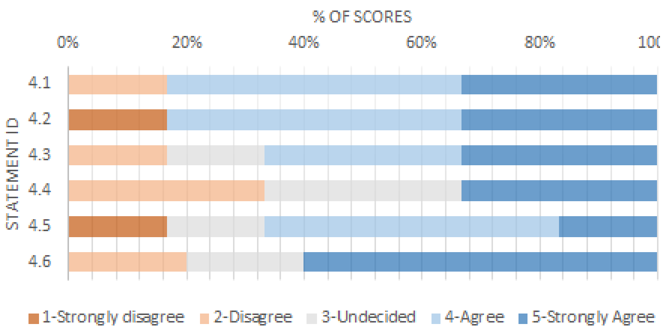


FIGURE 4.39: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT - ET

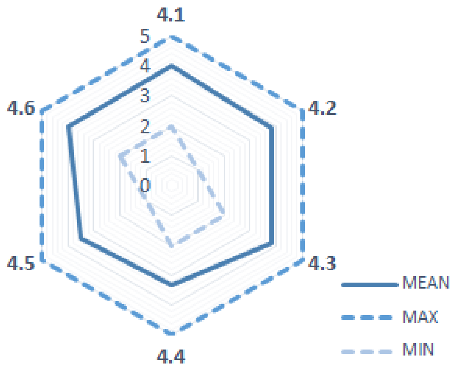


FIGURE 4.40: MEAN, MAXIMUM AND MINIMUM SCORES PER VALUE STATEMENT - ET

Figure 4.39 highlights over 80% of the users consider that the software allows the user full control of the design process (ID-4.1). Over 80% also agree that the tool produces results that allow easy comparisons (ID-4.2), although the remaining strongly disagree, which should be addressed. For the range of alternatives to create/assess technologies, just under 70% of the users agree that the tool provides a large range of alternatives to create/assess technologies (ID-4.3). Just over 30% of the users agree that the tool provides information about the internal processing (e.g. remaining time, log), with the remaining undecided or disagreeing (ID-4.4). Around 65% of the respondents agree that the software meets their expectations in terms of results, graphical options, interaction and functionality, while the rest are undecided (ID-4.5). 60% of the users would recommend using this tool (ID-4.6), with the rest undecided or disagreeing.

Figure 4.40 shows differences between the minimum and maximum scores for the same assessment criterion, which may be down to different perspectives and expectations of the respondents.

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 satisfaction*, *Unintended tool performance*, and *Proposals for improvement*. The aim of this section is to guide the path for improvement of the Energy Transformation (ET) module.

4.4.2.1 Overall user experience

Generally, the feedback indicated the Energy Transformation (ET) module is powerful, quite intuitive to use, fast and free of issues. However, the end-users highlighted that it could provide more help and guidance throughout the process and when visualising results. According to the feedback received, the following can be said about the overall user satisfaction:

- Overall, the ET module is perceived as intuitive, easy to use and efficient. The results are relevant and easy to interpret. Creating and deleting a Study is straightforward. There is full agreement on the excellent computation speed and running process without major issues. The training sessions and documentation helped to familiarise with the software.
- While the user interface is user-friendly and easy to navigate in general, users highlighted the need for further guidance throughout the process, simplification of data inputting if possible and increased clarity in results.
- Some users could not rate the performance and accuracy of the module. This might be due to the lack of detailed results in the Reference Models used for the verification cases. The available input data for the Power Take-off design was insufficient even for complexity 1, and many assumptions needed to be taken. As a result, there is no baseline to compare quantitative outputs with.
- The tool has a very comprehensive set of options. The functionality of the ET module can produce a large range of alternatives to design PTOs and facilitate comparison. However, users highlight the need for information about the internal processing and warnings about potential inconsistencies. The users suggested additional options for

the mechanical and electrical transformation steps. Also, using other format options for data export, such as csv format.

4.4.2.2 Unintended module performance

The tool behaved as expected; however, the following unintended issues were identified by some of the users:

- The hierarchy table for the array does not display in the taxonomy section.
- When creating a Study without a unique name, the inputs are lost. The user should be able to change the name and not need to re-enter all the data.

4.4.2.3 Proposals for improvement

USABILITY

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

- Remove the line for "Machine Characterisation study" in the "Create an Energy Transformation study" if the user has not provided the first two json files.
- The "-" and "+" buttons should be adjusted to relevant order of magnitude for the parameter considered (e.g. adding 1 unit to a 1,000,000 basis is not useful).
- In the "Analysis mode" window, clicking on the "select" button to access the study never worked the first time but worked immediately after refreshing the page.
- Globally, the software is intuitive, and the training sessions were useful to understand how to use the software.

USER-FRIENDLINESS

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

- Splitting "ET Studies" and "Analysis mode" is somehow confusing.
- Not clear why the rated power is entered 3 times for mechanical, electrical, and grid conditioning. It would be helpful if the pre-filled value for the later 2 were the same as entered in the first box, rather than typing it 3 times.
- Screen layout could be improved to make use of available space (e.g. Bill of Materials).
- The taxonomy panel could be directly integrated with a title for the section.
- Include the period used to estimate all the values in the output section (e.g. energy, damage, …).
- Several improvements could be made to the GUI to improve the experience for users, such as correct some typos (e.g. "materials"), overlapping of help messages (e.g. the help for 'bill of materials' obscures that for 'weight of the components'), output values between squared brackets, rounding of decimals (results should not display unwarranted precision).
- Please double-check the help "info" provided in each output. In some cases, it is incorrect.
- More GUI guidance on data inputs, complexity level compatibility and catalogues. For instance, better definition of device shutdown flag or Cpto / sigma_v, which are not

widely used, displaying clearly default values to be considered for each transformation step, providing the formula for the damage, electrical conversion class or "cosfi".
- When adding multiple studies consecutively, the filenames are still shown in the upload boxes, but they need to be added again.
- Power should be in kW or MW so there are not so many '000' to type (easy to enter 30kW instead of 300kW)
- Using json format for the export of results is not very user friendly, it would be nice to have csv format for the data too.
- The main point to be improved is the interface: the software is really good but the interface doesn't really look professional.

PERFORMANCE AND ACCURACY

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

- A percentage loss at each transformation stage could be included as part of the assessments.
- Plots of the results would be better to visualise the module assessment and allow comparisons.
- It is not expected that the control strategy is based solely on sea state, but it is understood why to opt for this simplified approach.
- The tool could provide feedback if the design is poor, e.g. if the power rating of the gearbox was far from optimal, resulting in a very inefficient design with high losses.

VALUE

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

- Add more PTO options such as a direct drive powertrain option (i.e. bypassing the gearbox) and other types of electrical generators (e.g. PMSG, DFIG).
- Allow the user to define the generator efficiency as a function of speed and torque.
- Rename "maximal to nominal torque" may be confusing, to "peak to nominal torque", as the maximum is sometimes a quadratic average or time-averaged value.
- For the grid conditioning, add the line filter inductance, resistance, capacitance, along with the type of filter (L, LCL, dvdt). Also, add the capacitance at the output of frequency converters and the DC bus, which affects damping.
- When running the tool, a message could be displayed to inform the user that the calculation has begun and shown the progress of the calculation. The user does not have an indication if the module is working after clicking on "Run".
- The GUI is different from other modules. For example, uploading files when creating the Study. Although this is intuitive, it is not what the user expects after having used other modules.

4.4.3 Identifying and solving inconsistencies

The feedback of the technical verifier and industrial partners was extremely useful to further improve the Energy Transformation module.

It is expected to implement most of the improvements suggested by the verifiers (High priority improvements listed in Table 4.25); There is another group of issues that, even if it would be useful to implement, may not be implemented due to lack of time (Lower priority improvements in Table 4.26). Finally, there are some others that will not be handled at the module level (but at the top level of the fully integrated version) or where design decisions are taken by the consortium, as shown in TABLE 4.27).

TABLE 4.25: HIGH PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF ET

Issue	Resolution
Remove the line for "Machine Characterisation study" in the "Create an Energy Transformation study" if the user has not provided the first two json files.	This suggestion will be implemented
The "-" and "+" buttons should be adjusted to relevant order of magnitude for the parameter considered (e.g. adding 1 unit to a 1,000,000 basis is not useful).	The precision will be revised in every variable of the GUI
Screen layout could be improved to make use of available space (e.g. Bill of Materials).	This improvement will be implemented
The taxonomy panel could be directly integrated in a title for the section.	This improvement will be implemented
Several improvements could be made to the GUI to improve the experience for users, such as correct some typos (e.g. "materials"), overlapping of help messages (e.g. the help for 'bill of materials' obscures that for 'weight of the components'), output values between squared brackets, rounding of decimals (results should not display unwarranted precision). Please double-check the help "info" provided in each output. In some cases, it is incorrect.	The suggested improvements will be analysed and corrected when possible
More GUI guidance on data inputs, complexity level compatibility and catalogues. For instance, better definition of device shutdown flag or Cpto / sigma_v, which are not widely used, displaying clearly default values to be considered for each transformation step, providing the formula for the damage, electrical conversion class or "cosfi".	Some of the proposed help will be provided in the GUI. The input formulation is quite complex and cannot be shown for clarity reasons

Issue	Resolution
When adding multiple studies consecutively, the filenames are still shown in the upload boxes, but they need to be added again.	This improvement will be implemented
Power should be in kW or MW, so there are not so many zeros to type (easy to enter 30kW instead of 300kW)	This power variables will be asked in kW
Add more PTO options such as a direct drive powertrain option (i.e. bypassing the gearbox) and other types of electrical generators (e.g. PMSG, DFIG).	New alternatives will be added
Rename "maximal to nominal torque" may be confusing, to "peak to nominal torque", as the maximum is sometimes a quadratic average or time-averaged value.	The description will be changed in the GUI
When running the tool, a message could be displayed to inform the user that the calculation has begun and shown the calculation progress. The user does not have an indication if the module is working after clicking on "Run".	This improvement will be implemented

TABLE 4.26: LOW PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF ET

Issue	Resolution
In the "Analysis mode" window, clicking on the "select" button to access the study never worked the first time but worked immediately after refreshing the page.	The problem will be analysed and corrected if possible
Include the period used to estimate all the values in the output section (e.g. energy, damage, ...).	If time available after high priority improvements are implemented, the resource information will be provided in the outputs
A percentage loss at each transformation stage could be included as part of the assessments.	This improvement is interesting but requires some internal changes. It will be assessed after higher priority improvements
Using the json format for the export of results is not user-friendly; it would be nice to have a csv format for the data.	This improvement will be analysed and carried out if possible
Plots of the results would be better to visualise the module assessment and allow comparisons.	Plots are desirable and will be implemented is time available
The tool could provide feedback if the design is poor, e.g. if the power rating of the gearbox was far from optimal, resulting in a very inefficient design with high losses	This improvement is desirable but complex. Feasibility will be analysed
Allow the user to define the generator efficiency as a function of speed and torque.	This improvement will be added if time available

TABLE 4.27: ISSUES THAT WILL NOT BE IMPLEMENTED IN THE BETA VERSION OF ET

Issue	Resolution and Explanation why it will not be implemented
Splitting "ET Studies" and "Analysis mode" is somehow confusing.	This suggestion will not be implemented as each page has different functionalities and may not be merged
Not clear why the rated power is entered 3 times for mechanical, electrical, and grid conditioning. It would be helpful if the pre-filled value for the later 2 were the same as entered in the first box, rather than typing it 3 times.	Each transformation step can have a different rated power
For the grid conditioning, add the line filter inductance, resistance, capacitance, along with the type of filter (L, LCL, dvdt). Also, add the capacitance at the output of frequency converters and the DC bus, which affects damping.	The filter is not part of Energy Transformation. On the other hand, the IGBT switching is not implemented (it would be very slow) as it is not necessary for the efficiency calculation. Thus, the capacitance is not needed.
The GUI is different from other modules. For example, uploading files when creating the Study. Although this is intuitive, it is not what the user expects after having used other modules	Modifying the graphical interface of the tool is out of the scope

4.5 RUNNING THE VERIFICATION CASES: Energy Delivery (ED)

4.5.1 Quantitative assessment

A total of 5 organisations completed the verification process for the different features of the ED module (WavEC, EDP, EGP, IDOM, Sabella) and provided feedback by the Software Evaluation Form. Figure 4.41 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 3,8 to 4,4.

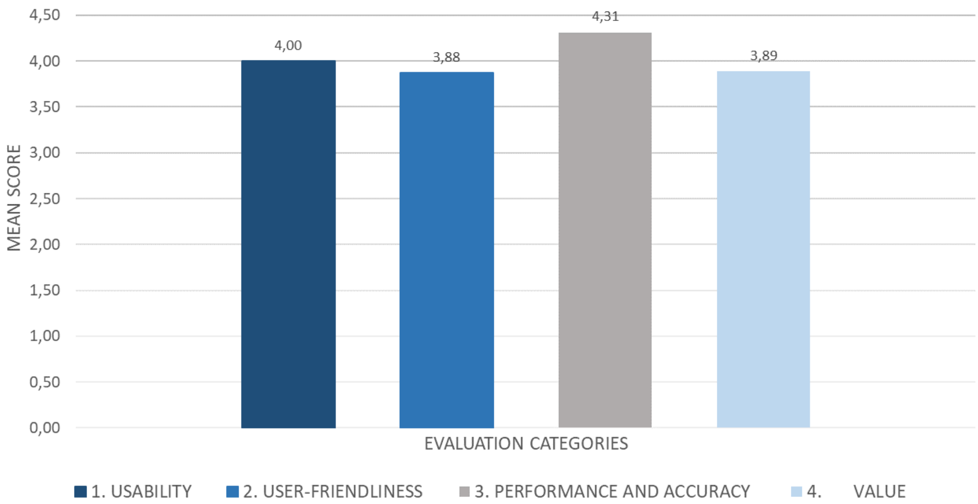


FIGURE 4.41: MEAN RATINGS OF THE EVALUATED CHARACTERISTICS - ED

As shown in Figure 4.42, most of the participants of verification (75%) were satisfied with the usability of the ED tool. The majority of (70%) the respondents agree or strongly agree that the tool is generally user friendly. Around 85% (in average) of the respondents agree that the tool shows performance and accuracy. Around 75% of the users considered that the tool is valuable, while around 15% disagree. Further analysis of the results is described in the following section.

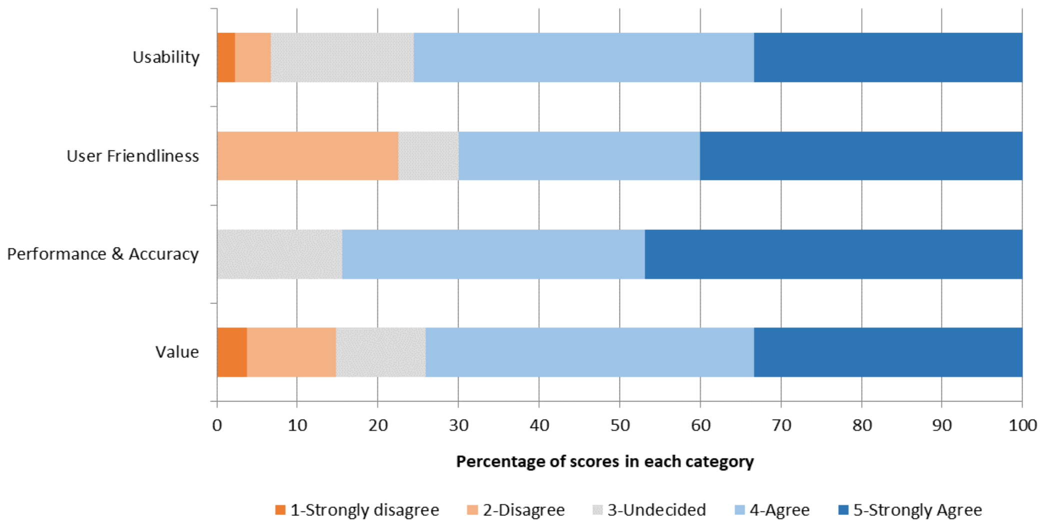


FIGURE 4.42: PERCENTAGE OF SCORES FOR THE FOUR KEY CATEGORIES - ED

4.5.1.1 Usability

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

TABLE 4.28: ASSESSED USABILITY CRITERIA - ED

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 4.43presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.44 using a spider chart, to highlight the mean, maximum and minimum values.

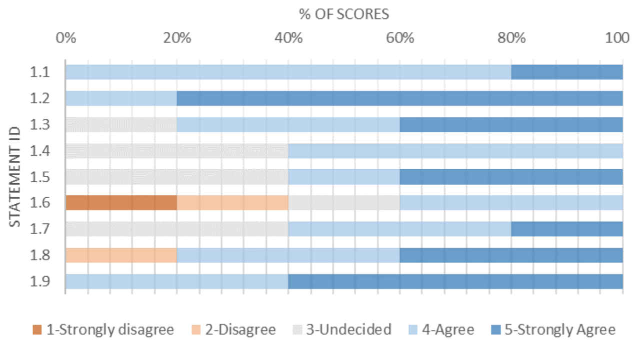


FIGURE 4.43: DISTRIBUTION OF USER SCORES PER USABILITY STATEMENT - ED

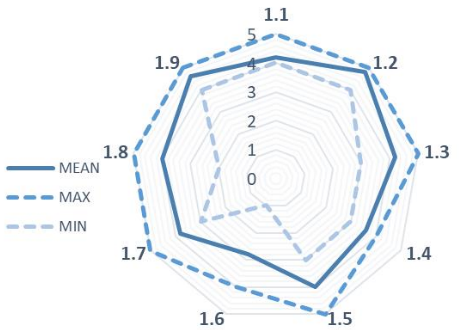


FIGURE 4.44: MEAN, MAXIMUM AND MINIMUM SCORES PER USABILITY STATEMENT - ED

All the users agree or strongly agree that: the tool is easy to use in general (ID-1.1); it's easy to create a study and delete it (ID-1.2); the training sessions and documentation are useful for learning how to use the software (ID-1.9). 80% of the respondents agree or strongly agree that it's easy to edit, save and export a study (ID-1.3), and the software can be run from their computer without any issue (ID-1.8). The other 20% are undecided for ID-1.3 and disagree on ID-1.8.

60% of the users agree or strongly agree that: the process of inputting data is clear and efficient (ID-1.4); the results are meaningful, easy to interpret and use (ID-1.5); the overall speed of computation is satisfactory (ID-1.7). The remaining user is undecided on these criteria. Finally, 40% of the respondents considered that they could complete the process without errors (ID-1.6), 20% are undecided, and 40% disagree or strongly disagree with this.

From the spider graph, it's possible to see that the mean values are well balanced for most of the criteria. In ID-1.6, the difference between the maximum and minimum values can be justified with different user experiences about this tool.

4.5.1.2 User Friendliness

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

TABLE 4.29: ASSESSED USER FRIENDLINESS CRITERIA - ED

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 4.45 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.46 using a spider chart, to highlight the mean, maximum and minimum values.

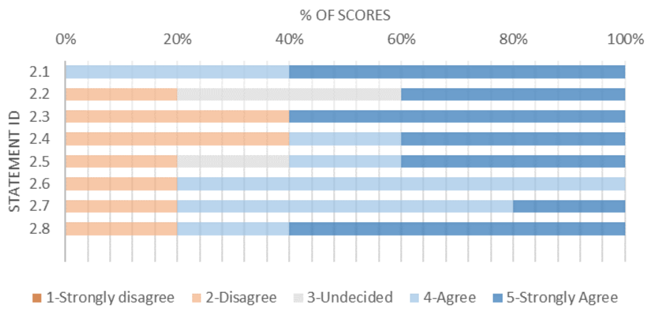


FIGURE 4.45: DISTRIBUTION OF USER SCORES PER USER-FRIENDLINESS STATEMENT - ED

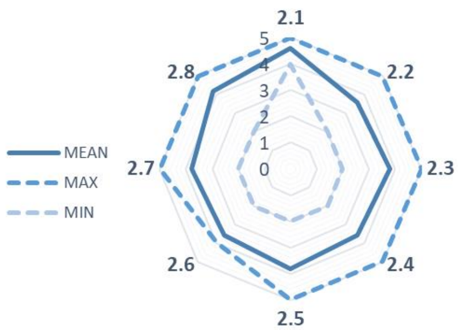


FIGURE 4.46: MEAN, MAXIMUM AND MINIMUM SCORES PER USER-FRIENDLINESS STATEMENT - ED

All the users agree or strongly agree that the user interface is simple, easy to navigate and well-organised (ID-2.1). 80% of the users agree or strongly that: the meaning of each data output is clear (ID-2.6); the visualisation of results is clear and informative (ID-2.7); the user can add further information to the Study through the interface (ID-2.8). The remaining users disagree on these criteria.

Around 60% of the respondents agree or strongly agree that: the tool responds promptly to user actions (inputs, selections, clicks, ...) (ID-2.3); the tool provides enough help, indications and/or guidance throughout each process (ID-2.4); the meaning of each data input/user selection is clear (ID-2.5). The other respondents disagree with this criteria ID-2.3 and ID-2.4. On criterion ID-2.5, 20% disagree, and 20% remained undecided.

The criterion ID-2.2, "the user interface looks professional," divided the users' opinions. 40% strongly agree, 40% are undecided, and 20% disagree on this.

From the spider graph, it's possible to see that the mean values are well balanced for all the criteria.

4.5.1.3 Performance and Accuracy

The following statements have been set as criteria for assessing the ED tool in terms of *Performance and Accuracy*. These criteria were applied to 3 different features of the tool: overall, low complexity and full complexity.

TABLE 4.30: ASSESSED PERFORMANCE AND ACCURACY CRITERIA - ED

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 4.47 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.48 using a spider chart to highlight the mean, maximum and minimum values. The results represent the average of the scores obtained in the three features – overall, low complexity and full complexity

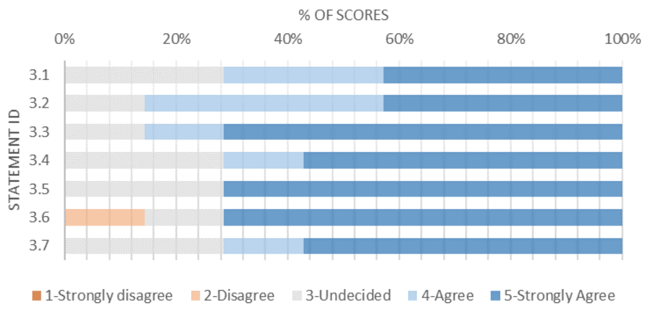


FIGURE 4.47: DISTRIBUTION OF USER SCORES PER PERFORMANCE AND ACCURACY STATEMENT - ED

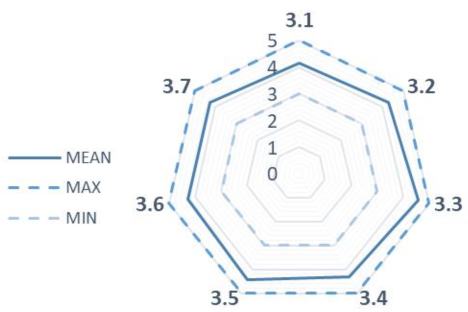


FIGURE 4.48: MEAN, MAXIMUM AND MINIMUM SCORES PER PERFORMANCE AND ACCURACY STATEMENT - ED

More than 85% of the users considered that the results are credible and trustworthy for the audience (ID-3.2), and the accuracy of results is acceptable considering the granularity/complexity of data inputs used (ID-3.3). The remaining users are undecided on these two criteria.

Around 70% of the respondents considered that: the results are robust and not sensitive to small changes of inputs (ID-3.1); the accuracy of results corresponds to the user expectation for the stage of technology maturity (ID-3.4); 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 (ID-3.6); the software can handle errors without crashing (ID-3.7). The other respondents are undecided for most of these criteria, except for criterion ID-3.6 that around 15% disagree, and around 15% were undecided.

From the spider chart and considering the mean values, we can state that the results obtained in this criteria assessment are well balanced and always above 4 – Agree.

4.5.1.4 Value

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

TABLE 4.31: ASSESSED VALUE CRITERIA - ED

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 4.49 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.50 using a spider chart to highlight the mean, maximum and minimum values.

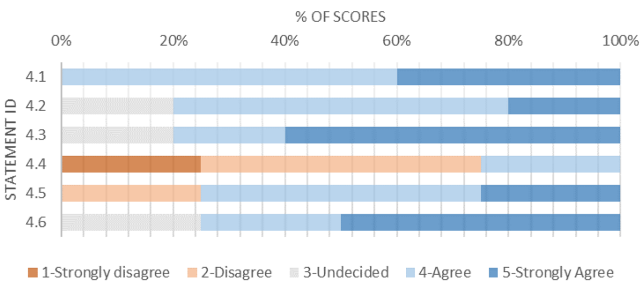


FIGURE 4.49: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT - ED

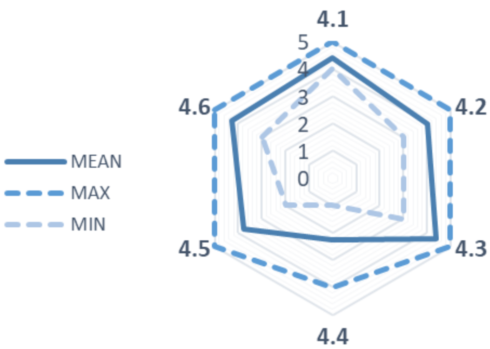


FIGURE 4.50: MEAN, MAXIMUM AND MINIMUM SCORES PER VALUE STATEMENT - ED

All the users agree or strongly agree that the software allows the user full control of the design process (ID-4.1). 80% of the respondents agree or strongly agree that the tool produces results that allow easy comparisons (ID-4.2), and the tool provides a large range of alternatives to create/assess technologies (ID-4.3). The other 20% of the users are undecided on these two criteria.

Around 75% of the respondents agree or strongly agree that the software meets the expectations in terms of results, graphical options, interaction, and functionality (ID-4.5) and recommend using this software (ID-4.6). The remaining respondents are undecided on these two criteria.

On criterion ID-4.4, "The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies", one quarter of the users strongly disagree, half of them disagree, and another quarter agrees.

From the spider chart, it can be seen that most of the criteria are well balanced in terms of the mean value. On criterion ID-4.4, some low scores were registered, and so, the mean value on this criterion was lower than the other ones.

4.5.2 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 Energy Delivery (ED) module.

4.5.2.1 Overall user experience

Generally, the feedback indicated the Energy Delivery (ED) module is useful and user-friendly, has a good level of accuracy, and offers value to users. The following points can be collated from the feedback received about the overall user satisfaction:

- Overall, the user interface was highly rated, with a few exceptions. Some users found there was not enough guidance throughout each process and that some of the terminology used for the input parameter labels was not clear. Further explanation of the input parameters would make the module more user friendly. This can also be linked to the documentation for further details. There was a similar error with the display of "uncaught" error messages not being clear.
- The default values used in the module calculation when optional parameters are not specified could be more clearly identified.
- When the module was running correctly, the computational time was judged acceptable, and it responded promptly; however, it was unacceptably unresponsive during the period it was not working, as discussed in the next subsection.
- In terms of performance and accuracy, the results were found to be robust, credible, and accurate. However, the use of json for the results complicates the inputs for new users.

- The results were generally found to be well presented, and the comparison between network options was welcomed. The display of the detailed network hierarchy was judged to be over-complex and not so useful.
- Several points were raised related with the use of json files for inputs, which is not so user-friendly. These are only required when the module runs in standalone mode to introduce data that would normally be an output of earlier modules. Therefore, this should not be a problem for the final integrated suite of tools. Additionally, importing and exporting from a csv format would also be a useful addition.

4.5.2.2 Unintended module performance

The tool mostly behaved as expected; however, the following "critical" aspects were identified by some of the users:

- During the period in which the verification of the Energy Delivery module was being conducted, a minor bug in the server configuration stopped the tool from working properly. Unfortunately, troubleshooting this took some time, and during this period, it was not possible to run the design process at all. As a workaround, some of the verification was conducted by reviewing previously computed results after creating new studies without the verifiers actually running the design algorithm. This still allowed most of the module functionality to be verified, with the exception of computational time.
- Some users had problems uploading the site inputs or found the performance of the module being slow. This may have been due to performance issues experienced on the server the software was being tested on, with other modules also using the computation resources.

4.5.2.3 Proposals for improvement

USABILITY

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

- The definition of input parameters could be improved with regards to naming, units used, and default values.
- Better handling or error messages and progress is required.

USER-FRIENDLINESS

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

- Using json format for the inputs is not the most user-friendly.
- Several improvements could be made to the GUI to improve users' experience, such as automatically loading the results page once the design process is complete or hiding blank tables of results when only one result option is presented.

PERFORMANCE AND ACCURACY

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

- Several issues were observed relating to the performance of the module on the test server, which should be improved when the module is running on a local computer without other modules, also using computation resources.
- The input and plotting of large bathymetry files can be slow and would be improved with a progress bar.
- The length of time taken to complete the full complexity design process was judged long by some users, especially as progress with this is not well communicated to the user.

VALUE

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

- The format of the results could be improved, including the hierarchy and cable data.
- Being able to import and export results to csv/Excel data format would also add value.

4.5.3 Identifying and solving inconsistencies

The feedback of the technical verifier and industrial partners was extremely useful to further improve the Energy Delivery module.

We expect to implement most of the improvements suggested by the verifiers (high priority improvements, in Table 4.32); however, there are others that, even if it would be useful to implement, may not be implemented due to lack of time (lower priority improvements in

Table 4.33). Finally, there are some others that cannot be implemented because they are not in the scope of the ED module (they are in the scope of the main application) or were the result of design decisions taken by the consortium, as shown in Table 4.34).

TABLE 4.32: HIGH PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF ED

Issue	Resolution
There is ambiguity between complexity levels 2 and 3, as these have the same input requirements.	Clarify in the GUI that the difference reflects the user's confidence in the inputs used.
Some of the input parameter names are not clear and/or could do with more explanation. Some of the inputs have inconsistent units, e.g. (m,m) for the array layout in json format.	Terminology and units to be reviewed and updated. Add descriptions via a help icon or similar, possibly linked to the documentation.
Data entry for array layout is difficult for the user, as it requires typing or copy/pasting a json string in the input box.	Implement a json file upload for this to remove the need for manual data entry.

Issue	Resolution
Not clear what default values are used in the design process if an optional parameter is not specified	Default values for optional parameters such as footprint radius could be pre-filled for the user to update if necessary
DR import/export functionality not yet implemented	Work in progress to implement this.
Blank error messages were displayed in the GUI.	This was due to the bug in the server deployment, which has now been fixed. The design process has been made an asynchronous operation, which should prevent timeout errors. Improve error handling of BE/BL. Ensure any error in the BE/BL is shown through the GUI.
API requests when the module is running on the server are sometimes slow, resulting in a long time to populate the list of studies, inputs, etc.	This issue is only seen on the server implementation and not when running locally. Test local installation to ensure that this issue is not present when running locally.
Footprint radius of zero could be entered in the inputs, which caused the design to fail.	Data input check for radius bigger than zero has now been implemented.
The network hierarchy list presented in the results is not clear to an end user	Mark this as an 'advanced' result, as most users do not need to understand this. An alternative representation will be considered if time allows.
The results view refers to 'marker', which is not defined. This is an internal component ID.	Review and updated terminology used in results.
Some output formats in the results view are not user friendly for further processing or analysis.	Allow all data to be download in json format.
The user might want to consider another network option than what is proposed as the best/optimal network option ranked by partial cost of energy delivered, especially where the results are close.	In the integrated tool, the user should be able to choose which network to take forward for further analysis.

TABLE 4.33: LOW PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF ED

Issue	Resolution
Due to a large number of bathymetry points, the corresponding json file is big and hence takes a while to load and plot.	The possibility of plotting just the lease and export area boundaries will be explored, as this should speed up the plotting.
Using json format, or (x,y,z) triplets for device array layout co-ordinates etc. is cumbersome and potentially error prone, this could be replaced by a series of input boxes.	This will not be required in integrated mode and only applies to standalone. A consistent approach is used in all modules. However, a pre-processor to convert from csv to json could be provided.
Not easy to know what the co-ordinates should be without a visualisation	Show a figure whenever coordinates are requested.
The process of loading large input files can take a long and indeterminate length of time	Add a progress bar when loading files

Issue	Resolution
The process of creating studies with large input files can take a long and indeterminate length of time	Add a progress bar when creating studies
Not clear how long the calculation process will take. For complex designs, this can take several minutes, with no indication of progress.	Implement a progress bar to visualise the calculation time remaining. Display python logging data in the GUI, which will provide an update on the status.
The user can click the 'view results' button before the analysis is complete, which displays a blank results page.	Disable the 'view results' button until the results are available.
The user has to click 'view results' after the system design and analysis process is complete.	Automatically show the results once the design is complete
Placeholders for the results of network options 2 & 3 are shown, even when there is only a single network result returned.	Hide the results tables when they are not used
Legend on the network schematic visualisation sometimes obscures part of the design	Revise the visualisation so the legend does not obstruct the design
The network hierarchy list presented in the results is not clear to an end user	Look at alternative ways to represent the hierarchy
Some output formats in the results view are not user friendly for further processing or analysis.	Allow selective data down in csv/Excel format in addition to json

TABLE 4.34: ISSUES THAT WILL NOT BE IMPLEMENTED IN THE BETA VERSION OF ED

Issue	Resolution and Explanation why it will not be implemented
Copying/duplicating studies to facilitate testing slightly different studies would be a useful addition.	This is within the scope of the main module.
The units do not change to reflect the order-of-magnitude of the result, e.g. always kW but do not change to MW where appropriate.	A design decision was made to use consistent units across all modules.

4.6 RUNNING THE VERIFICATION CASES: Station Keeping (SK)

4.6.1 Quantitative assessment

A total of 7 organisations completed the verification process for the different features of the SK module (EDP, Corpower, NOVA, BV, Sabella, IDOM, EGP) and provided feedback by the Software Evaluation Form. Figure 4.51 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 4 to 5.

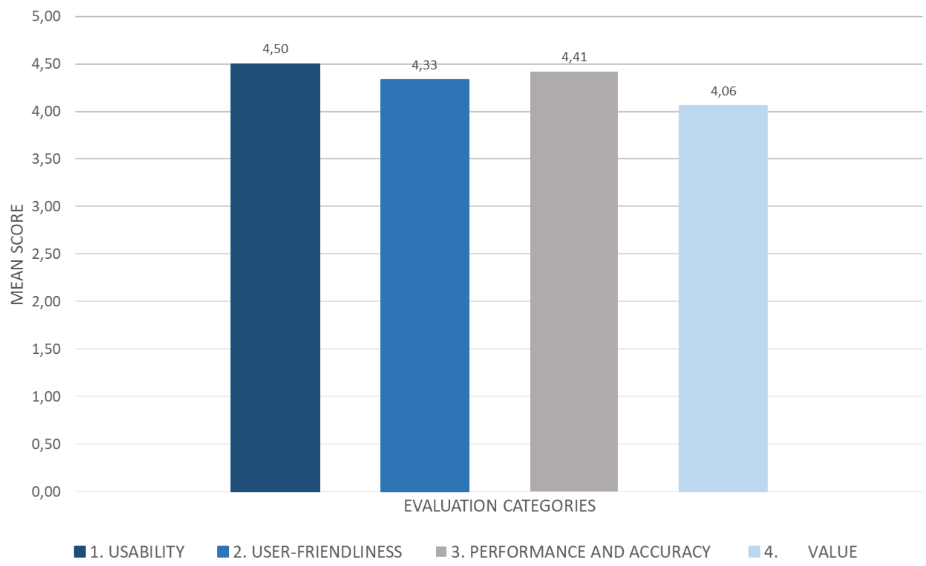


FIGURE 4.51: MEAN RATINGS OF THE EVALUATED CHARACTERISTICS - SK

As shown in Figure 4.52, most of the participants of verification (almost 90%) were satisfied with the usability of the SK tool. The majority of (more than 80%) the respondents agree or strongly agree that the tool is generally user friendly. More than 90% (in average) of the respondents agree that the tool shows performance and accuracy. Around 75% of the users considered that the tool is valuable, while around 3% disagree. Further analysis of the results is described in the following sections.

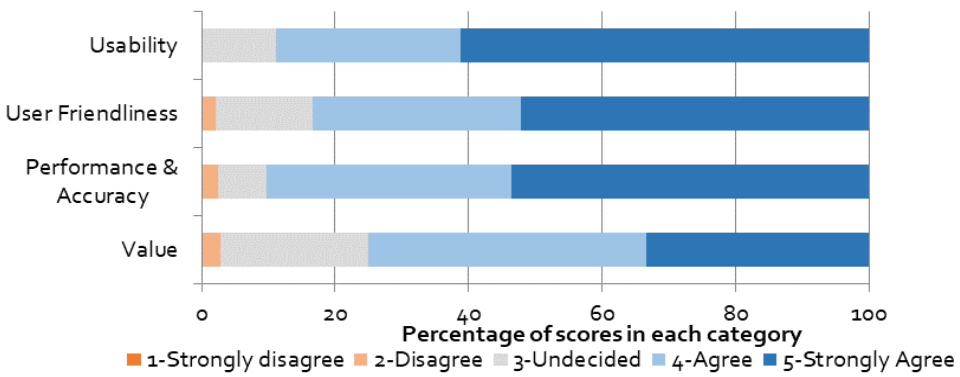


FIGURE 4.52: PERCENTAGE OF SCORES FOR THE FOUR KEY CATEGORIES - SK

4.6.1.1 Usability

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

TABLE 4.35: ASSESSED USABILITY CRITERIA - SK

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 4.53 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.54 using a spider chart to highlight the mean, maximum and minimum values.

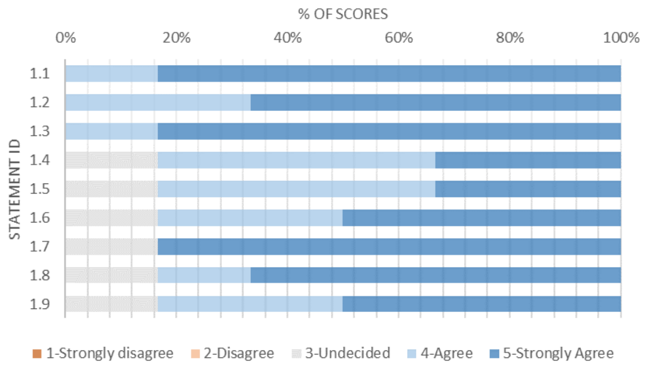


FIGURE 4.53: DISTRIBUTION OF USER SCORES PER USABILITY STATEMENT – SK

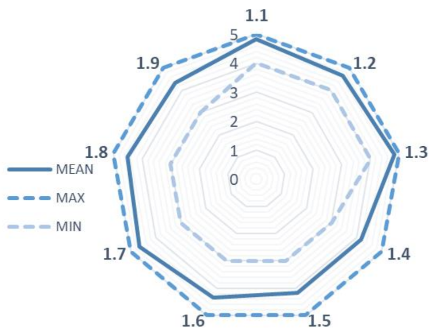


FIGURE 4.54: MEAN, MAXIMUM AND MINIMUM SCORES PER USABILITY STATEMENT - SK

The majority of the users shows a positive feedback to most of the evaluation items in the feature "Usability". All the users strongly agree or agree that the tool is easy to use in general, it's easy to create a study and delete it, and it's also easy to edit, save and export a study (ID-1.1, ID-1.2, ID-1.3).

More than 80% of the testers considered that: the process of inputting data is clear and efficient (ID-1.4); the results are meaningful, easy to interpret and use (ID-1.5); could complete the process without errors (ID-1.6); the overall speed of computation is satisfactory (ID-1.7); the software can be run from their computer without any issue (ID-1.8); the training sessions and documentation are useful for learning how to use the software (ID-1.9). The remaining ones were undecided on these criteria.

From the spider graph, it's possible to assume that the criteria were well balanced, revealing a mean value always above 4 – Agree.

4.6.1.2 User Friendliness

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

TABLE 4.36: ASSESSED USER FRIENDLINESS - SK

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 4.55 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.56 using a spider chart to highlight the mean, maximum and minimum values.

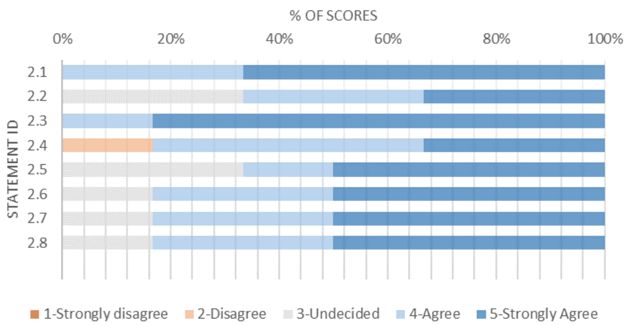


FIGURE 4.55: DISTRIBUTION OF USER SCORES PER USER-FRIENDLINESS STATEMENT - SK

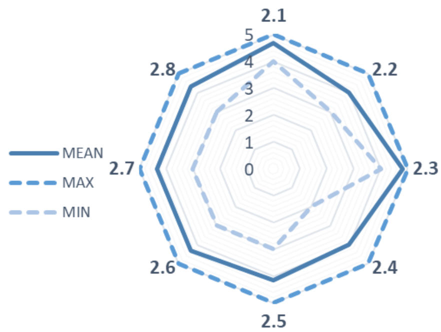


FIGURE 4.56: MEAN, MAXIMUM AND MINIMUM SCORES PER USER-FRIENDLINESS STATEMENT - SK

All the users strongly agree or agree that the user interface is simple, easy to navigate and well-organised (ID-2.1) and that the tool responds promptly to user actions (inputs, selections, clicks, …) (ID-2.3).

Around 67% of the users strongly agree or agree that the tool provides the user interface looks professional (ID-2.2) and that the meaning of each data input/user selection is clear (ID-2.5). The other respondents remained undecided.

Regarding criterion ID-2.4, more than 85% agree or strongly agree that the tool provides enough help, indications, and/or guidance throughout each process, while the rest disagree with this.

More than 80% of the respondents agree or strongly agree that: the meaning of each data output is clear (ID-2.6); the visualisation of results is clear and informative (ID-2.7); the user can add further information to the Study through the interface (ID-2.8). The remaining ones are undecided on these criteria.

From the spider graph it's possible to gauge that despite the low minimum value registered on criterion ID-2.4, the average classification in all the criteria was satisfactory.

4.6.1.3 Performance and Accuracy

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

TABLE 4.37: ASSESSED PERFORMANCE AND ACCURACY CRITERIA - SK

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 4.57 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.58 using a spider chart to highlight the mean, maximum and minimum values.

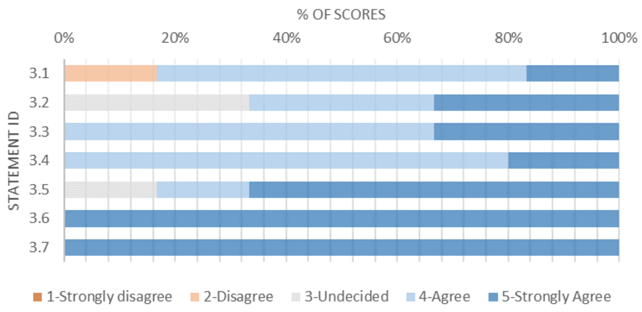


FIGURE 4.57: DISTRIBUTION OF USER SCORES PER PERFORMANCE AND ACCURACY STATEMENT - SK

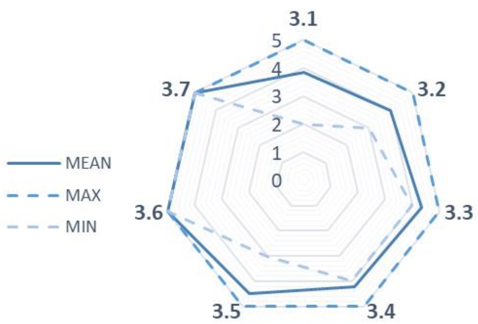


FIGURE 4.58: MEAN, MAXIMUM AND MINIMUM SCORES PER PERFORMANCE AND ACCURACY STATEMENT - SK

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 accuracy of results corresponds to the user expectation for the stage of technology maturity (ID-3.4); the software did not suffer from any sort of data shortage/lack of memory during the test (ID-3.6); the software can handle errors without crashing (ID-3.7).

Regarding results, credibility and trust for the audience (ID-3.2), two thirds of the respondents agree or strongly agree with it and for the computational time be adequate for the level of accuracy provided (ID-3.5), more than 85% agree or strongly agree. In both cases, the rest of the users were undecided.

About results being robust and not sensitive to small changes of inputs (ID-3.1), more than 80% agree or strongly agree, while the remaining ones disagree on this.

From the spider chart and considering the mean values we can state that the results obtain in this criteria assessment were all placed between 4 – agree and 5 – strongly agree. Just highlight the results obtained in criteria ID-3.6 and ID-3.7 where consensus was achieved between all the respondents.

4.6.1.4 Value

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

TABLE 4.38: ASSESSED VALUE CRITERIA - SK

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 4.59 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.60 using a spider chart, to highlight the mean, maximum and minimum values.

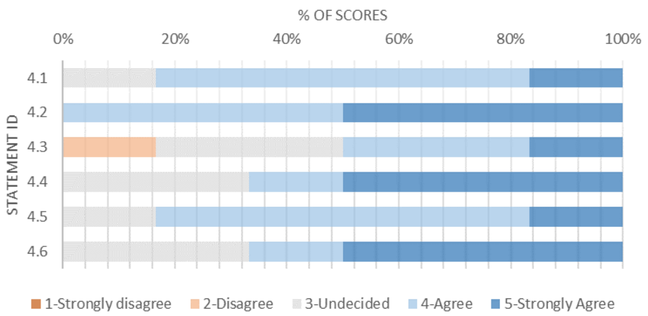


FIGURE 4.59: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT – SK

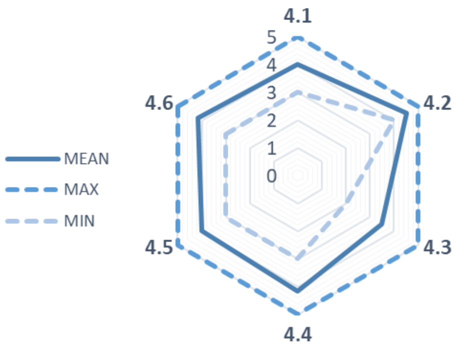


FIGURE 4.60: MEAN, MAXIMUM AND MINIMUM SCORES PER VALUE STATEMENT - SK

More than 80% of the users agree or strongly agree that the software allows the user full control of the design process (ID-4.1) and that the software meets the expectations in terms of results, graphical options, interaction, and functionality (ID-4.5). The remaining respondents were undecided.

Two thirds of the respondents agree or strongly agree that the user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies (ID-4.4) and that would recommend the use of this software (ID-4.6). The rest of the users are undecided on these two criteria.

All the users agree or strongly agree that the tool produces results that allow easy comparisons (ID-4.2). Only 50% of the users considered that the tool provides a large range of alternatives to create/assess technologies (ID-4.3), while the other 50% remained undecided or disagree.

From the spider chart, we can state that despite the minimum value registered on criterion ID-4.3, the mean values presented for all the criteria are satisfactory.

4.6.2 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 Station Keeping (SK) module.

4.6.2.1 Overall user experience

Generally, the feedback indicated that the Station Keeping (SK) module is useful and quite intuitive to use. 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 SK module is perceived as intuitive and easy to use in general. The results are meaningful and easy to interpret. The software can be easily run, and the overall computation speed is satisfactory.
- While the user interface is clear, the users had difficulties in understanding some inputs and their meanings. It was highlighted that the SK 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 satisfactory as judged by all users in terms of accuracy, robustness and performance. For some results, such as "Design assessment" results, users would like to have more information. This can be easily done by displaying more results that are available as outputs of the module.
- The functionalities of the SK module are seen as a good screening tool, useful to assess the relevance of technological choice quickly.

4.6.2.2 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 computational time was sometimes very slow, preventing them from running the module. These issues originated from the host server and not the SK module itself.
- Users have encountered errors without any meaningful description of the source of the problem. Most of those errors originated from a bad or incomplete definition of an input by the user. More input data quality checks have been added to help the user understand the source of the error.

4.6.2.3 Proposals for improvement

GENERAL REMARKS

The verifiers have identified the following areas of general improvement:

- The welcome page should contain more information about the goal and functionalities of the SK module, required inputs and expected outputs.
- The process of defining the input data requires more guidance.
- Some options require some explanation, in particular the consequences on the results.

USABILITY

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

- The usability can be quickly increased by adding a link to a user manual in the GUI. In particular, some inputs are not clearly defined in the GUI.
- It would be useful to improve the "export to pdf" functionality: it is not working properly in the current version.
- Some results would benefit from a short explanation in the GUI. In particular, when the type of foundation is selected automatically by the module, it can lead to unrealistic results: this should be explained to the user.
- Some "wording" could be fixed to be consistent through the SK module, in particular the 'shallow' foundation, which is the same as the 'gravity based' foundation.
- When some required data is missing or inconsistent, the GUI should give a warning to the user. This is particularly true for the definition of the Rotor Thrust Coefficient Curve, in case a tidal machine is defined.

USER-FRIENDLINESS

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

- Switching from one input page to another might appear to be slow. This is due to the overload of the server during the verification test period, not specifically to SK module performances.
- There is a general need for more documentation in the GUI, and a proper user manual, in order to understand the meaning of each input. Additional sketch/drawing illustrating the definition and sign of some input variable might also help a lot the user.
- The page for creating/loading is not clear enough: the user doesn't know if they need to modify inputs from a previous study or create a new one. This requires guidance.
- The GUI would benefit from more visualization of the input data defined by the user. We can mention the rotor thrust coefficient curve, the layout of the farm.

PERFORMANCE AND ACCURACY

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

- The users have reported some modelling functionalities that they would like to see in the tool:
  - Defining rotor of different diameters on the same machine.
  - Defining different direction for wind/waves/current in ULS analysis (and not only colinear weather as in the current version).
  - Include the possibility to model gravity based foundation with spikes on rock seabed.
  - Include the possibility to define the mean wave drift force coefficients manually
  - Include the possibility to choose the material of the foundation.
- The difference between the levels of complexity and the consequences on the accuracy is not clear.
- Users would find it useful to model the fact that the rotor can be misaligned with the current.
- Some users would recommend that the orbital velocity of the wave can be added to the current velocity for the ULS analysis of the tidal machine.
- Fatigue analysis of the foundation would be a great added value to the tool.

VALUE

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

- The software should have a more contextual description and help/ glossary.
- It would be valuable to report the mooring's weight in the *Design Assessment* result section.
- The user confidence would be increased if the GUI could present the user's input graphically, for example, a 3D visualisation of the device, mooring system, and environment direction.

4.6.3 Identifying and solving inconsistencies

TABLE 4.39: HIGH PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF SK

Issue	Resolution
Include the possibility to model gravity based foundation with spikes on rock seabed	This will be implemented
Add a contextual description of the tool on the module home page	This will be implemented
Fix bugs when exporting results to pdf	This will be implemented
Add link to user and theory manual in the GUI. This will also document the consequences of choosing a level of complexity	This will be implemented
Ask confirmation when the user wants to delete a project	This will be implemented
Add a previous page button	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 a small description and link to a manual for more information
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
Add visualization of rotor thrust coefficient curve	This will be implemented
Add visualization of the farm layout	This will be implemented
Modify the 'load project' section to make it more intuitive	This will be implemented
Add guidance on each page about the meaning and consequences of the inputs and options chosen by the user	This will be implemented
Add a warning when the user selects 'automatic foundation type selection.'	This will be implemented
Add wave orbital velocity to the current velocity in the rotor force	This will be implemented as an option that the user can choose
Implement the possibility to define any material type for the gravity base foundation	This will be implemented

Improve the GUI layout (align input fields, for example)	We will align the input fields as much as possible and maybe create more specific sections to group the data inputs in a more well-organized way
Input data check for rotor thrust coefficient curve	This will be implemented
Add mooring weight to design assessment result	This will be implemented

TABLE 4.40: LOW PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF SK

Issue	Resolution
Add the possibility to define non-colinear environments in ULS analysis	This will be implemented if there is enough time
Add the visualization of the user defined inputs (device, seabed, environment direction)	This will be implemented if there is enough time
Implement the possibility to define manually the mean wave drift coefficients	This will be implemented 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

TABLE 4.41: ISSUES THAT WILL NOT BE IMPLEMENTED IN THE BETA VERSION OF SK

Issue	Resolution and Explanation why it will not be implemented
Defining the rotor of different diameters on the same machine	This will not be included in the beta version due to a lack of time but will be considered in the future development of the tool
Implement the possibility to model misaligned rotor-current	This would require too much work as this would also require developments in other DTO+ modules. It is, therefore, to be considered as future work
Implement fatigue analysis of foundation	This cannot be implemented in a simple manner in this module

4.7 RUNNING THE VERIFICATION CASES: Logistics and Marine Operations (LMO)

4.7.1 Quantitative assessment

A total of 6 organisations completed the verification process for the different features of the LMO module (AAU, WES, Sabella, BV, IDOM, EGP) and provided feedback by the Software Evaluation Form. FIGURE 4.61 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 4.

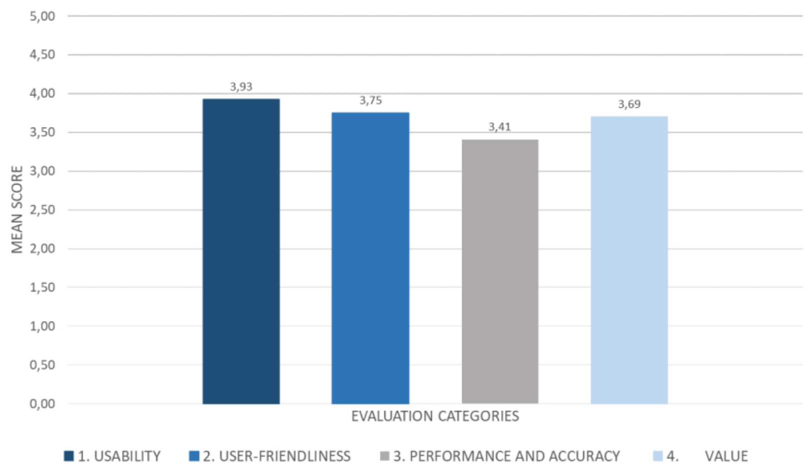


FIGURE 4.61: MEAN RATINGS OF THE EVALUATED CHARACTERISTICS - LMO

As shown in Figure 4.62, most of the participants of verification (>70%) were satisfied with the usability of the LMO tool. The majority of (more than 60%) the respondents agree or strongly agree that the tool is generally user friendly. More than 50% (in average) of the respondents agree that the tool shows performance and accuracy. Almost 60% of the users considered that the tool is valuable, while around 20% disagree. Further analysis of the results is described in the following sections.

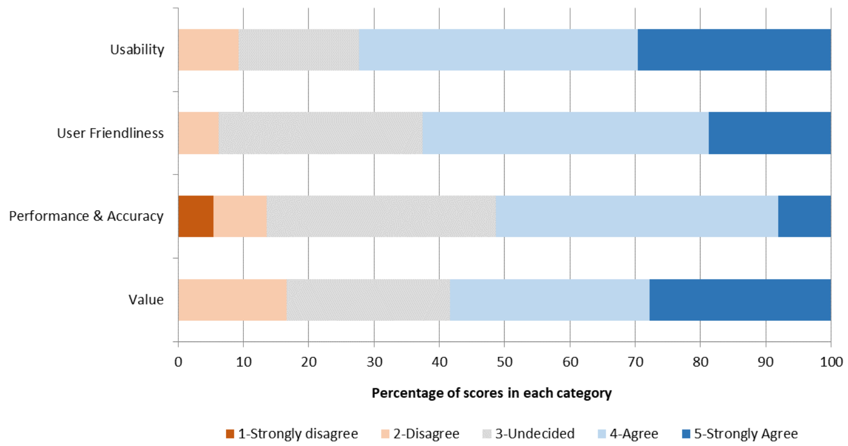


FIGURE 4.62: PERCENTAGE OF SCORES FOR THE FOUR KEY CATEGORIES - LMO

4.7.1.1 Usability

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

TABLE 4.42: ASSESSED USABILITY CRITERIA - LMO

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 4.63 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.64 using a spider chart to highlight the mean, maximum and minimum values.

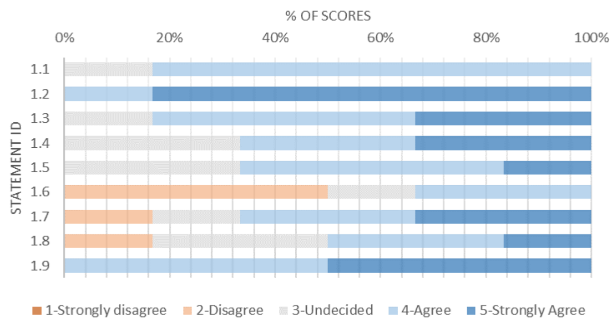


FIGURE 4.63: DISTRIBUTION OF USER SCORES PER USABILITY STATEMENT - LMO

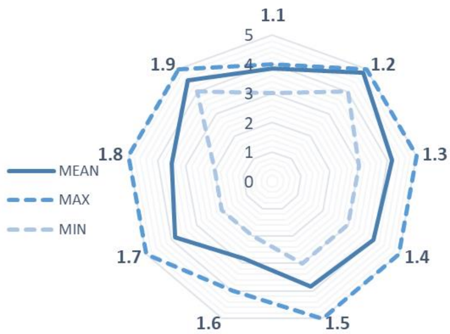


FIGURE 4.64: MEAN, MAXIMUM AND MINIMUM SCORES PER USABILITY STATEMENT - LMO

All the users agree or strongly agree that it's easy to create a study and delete it (ID-1.2), and the training sessions and documentation are useful for learning how to use the software (ID-1.9). More than 80% of the respondents agree or strongly agree that the tool is easy to use in general (ID-1.1), and it's also easy to edit, save and export a study (ID-1.3). The remaining respondents are undecided on these two criteria.

Two thirds of the users agree or strongly agree that the process of inputting data is clear and efficient (ID-1.4), and the results are meaningful, easy to interpret and use (ID-1.5). The other third remained undecided on these assessment criteria.

For ID-1.6, "I could complete the process without errors", half of the respondents disagree, while the other half is undecided or agree. Around 17% of the users disagree that computation's overall speed is satisfactory (ID-1.7), and the software can be run from their computer without any issue (ID-1.8). The other users were undecided, agreed or strongly agreed with these criteria.

From the spider graph, it's possible to assume that the criteria were well balanced, except for criterion ID-1.6 were the mean value was below 3 – Undecided.

4.7.1.2 User Friendliness

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

TABLE 4.43: ASSESSED USER FRIENDLINESS CRITERIA - LMO

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 4.65 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.66 using a spider chart to highlight the mean, maximum and minimum values.

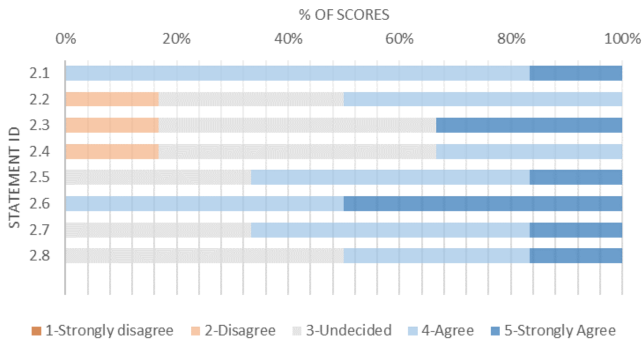


FIGURE 4.65: DISTRIBUTION OF USER SCORES PER USER-FRIENDLINESS STATEMENT - LMO

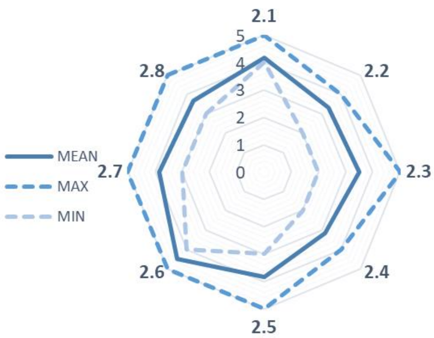


FIGURE 4.66: MEAN, MAXIMUM AND MINIMUM SCORES PER USER-FRIENDLINESS STATEMENT - LMO

All the users agree or strongly agree that the user interface is simple, easy to navigate and well-organised (ID-2.1), and of the respondents agree or strongly agree that: the meaning of each data output is clear (ID-2.6).

Two thirds of the respondents agree or strongly agree that the meaning of each data input/user selection is clear (ID-2.5) and the visualisation of results is clear and informative (ID-2.7). One third are undecided on these criteria. On ID-2.8, "The user can add further information to the Study through the interface", 50% of the users are undecided while the other half agree or strongly agree with it.

Around 17% of the users disagree that: the user interface looks professional (ID-2.2); the tool responds promptly to user actions (inputs, selections, clicks, …) (ID-2.3); the tool provides enough help, indications and/or guidance throughout each process (ID-2.4). The rest of the users are undecided or agree with this for ID-2.2 and ID-2.4 and are undecided or strongly agree for ID-2.3.

From the spider graph, it's possible to gauge that despite the low minimum value registered on criteria ID-2.2, ID-2.3 and ID2.4, the average classification in all the criteria were satisfactory.

4.7.1.3 Performance and Accuracy

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

TABLE 4.44: ASSESSED PERFORMANCE AND ACCURACY CRITERIA - LMO

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 4.67 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.68 using a spider chart, to highlight the mean, maximum and minimum values.

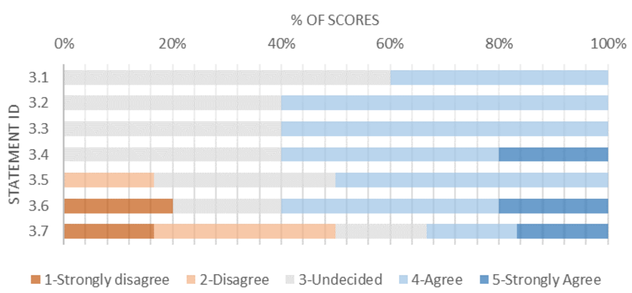


FIGURE 4.67: DISTRIBUTION OF USER SCORES PER PERFORMANCE AND ACCURACY STATEMENT - LMO

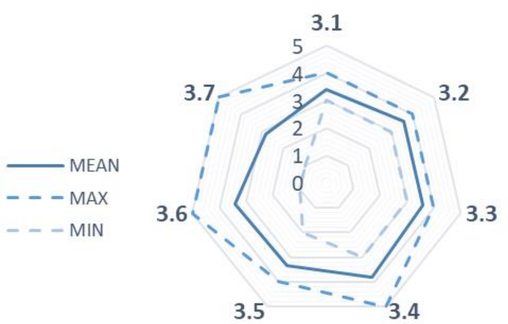


FIGURE 4.68: MEAN, MAXIMUM AND MINIMUM SCORES PER PERFORMANCE AND ACCURACY STATEMENT - LMO

About 60% of the users agree that the results are credible and trustworthy for the audience (ID-3.2), and the accuracy of results is acceptable considering the granularity/complexity of data inputs used (ID-3.3). The other users are undecided on these criteria. Again, 60% of the respondents agree or strongly agree that the accuracy of results corresponds to the user expectation for the stage of technology maturity (ID-3.4), and the software did not suffer from any data shortage/lack of memory during the test (ID-3.6). The rest of the respondents are undecided on ID-3.4, and for ID-3.6, 20% are undecided, and 20% strongly disagree.

One third of the users agree or strongly agree that the software can handle errors without crashing (ID-3.7), one third disagree on this, and the rest of them are undecided or strongly disagree. 40% of the respondents agree that the results are robust and not sensitive to small changes of inputs (ID-3.1), while the rest of them are undecided on this criterion. Finally, half of the users agree that the computational time is adequate for the level of accuracy provided (ID-3.5), one third of them are undecided, and around 17% strongly disagree on this criterion.

Analysing the spider chart, it's possible to see that the mean scores obtained are not well balanced. Also, in criteria ID-3.6 and ID-3.7, the consensus is far from being achieved. This can be justified as different user expectations on the *Performance and Accuracy* of the tool.

4.7.1.4 Value

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

TABLE 4.45: ASSESSED VALUE CRITERIA - LMO

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 4.69 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.70 using a spider chart to highlight the mean, maximum and minimum values.

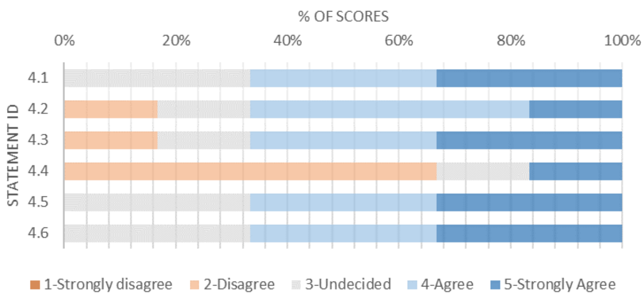


FIGURE 4.69: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT - LMO

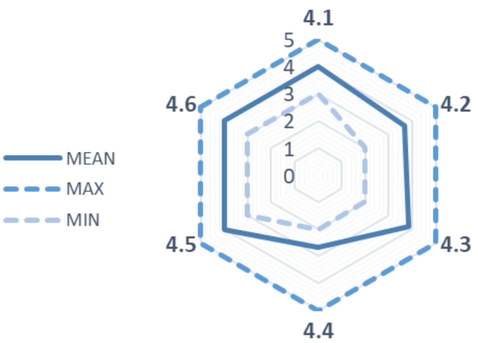


FIGURE 4.70: MEAN, MAXIMUM AND MINIMUM SCORES PER VALUE STATEMENT - LMO

Two thirds of the users agree or strongly agree that: the software allows the us er full control of the design process (ID-4.1); the tool produces results that allow easy comparisons (ID-4.2); the tool provides a large range of alternatives to create/assess technologies (ID-4.3); the software meets the expectations in terms of results, graphical options, interaction, and functionality (ID-4.5); would recommend the use of this software (ID-4.6). The rest of the users are undecided (ID-4.1, ID-4.2, ID-4.3, ID-4.5, ID-4.6) or disagree (ID-4.2, ID-4.3).

Again, two thirds of the respondents disagree that the user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies (ID-4.4). The remaining ones are undecided or strongly agree with this criterion.

From the spider chart is possible to state that the mean values obtained are well balanced, except for criterion ID-4.4.

4.7.2 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 Logistics and Marine Operations (LMO) module.

4.7.2.1 Overall user experience

The Logistics and Marine Operations module is a computationally intensive tool. This caused some sporadic crashes and bugs when running on the OCC server due to a shortage of server RAM, when multiple users were testing the module simultaneously. This affected the user experience of the testers on the OCC server and consequently the scoring and feedback. However, verification partners that tested the module on their local machines (i.e. WES) did not experience such memory crash problems.

Generally, the feedback indicated that overall, the tool is valuable, but some improvements are required. According to the comments received, the following can be said about the overall user satisfaction:

- Users highlighted the importance of visualizing what inputs were introduced.
- Users highlighted the importance of obtaining feedback about the computation progress and estimated time left.
- The training video and provided documentation were helpful
- Gantt charts are a nice feature

4.7.2.2 Unintended module performance

User experience was greatly impacted by the unexpected server behaviour (memory crashes and freezes) when a larger number of users were testing the module simultaneously. While this problem will not occur on the final desktop version of the LMO module, the following 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. In the Project initial page (1), modifying the inputs after having previously run the module led to errors (unlock button was not deleting the results). This problem was fixed.
3. The results page occasionally did not load automatically, requiring the user to press refresh to visualize the results. This problem will be fixed.
4. On the final results page, the "view results" button did not always register the clicks. This problem was fixed.

4.7.2.3 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, button labels, and correction of typos.
- Resolution of memory leakage bugs and crashes.
- Improvements in the user experience while navigating and introducing inputs into the GUI through:
  - Validation of input files uploaded by the user (to validate if an incorrect file has been uploaded).
  - 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.

- The implementation of feedback about the expected computation time
- Improve visualisation and handling of outputs:
  - Improve the presentation of results (e.g. Installation and Maintenance result tables, as well as Gantt charts).
  - Ability to visualize which inputs had been selected and led to these outputs
  - Present additional outputs on the result tables, namely the name of the vessels and ports.
- Implement functionalities that were not available at the time of the verification process:
  - Ability to export the study results
  - Functionality to export the digital representation.

4.7.3 Identifying and solving inconsistencies

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

We expect to implement most of the improvements suggested by the verifiers (high priority improvements, in Table 4.46); 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 4.47). Finally, there are some others that cannot be implemented because either they are not in the scope of the LMO module (e.g. they are in the scope of the main application), as shown in Table 4.48.

TABLE 4.46: HIGH PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF LMO

Issue	Resolution
Modifying the complexity level or name of the study when some inputs already have been introduced creates problems and errors.	This was caused by the memory shortage of the OCC server by having multiple users running the module simultaneously. This is no longer a problem
Some buttons should be relabelled, namely the "create" one, which should be changed to "save"	This will be implemented
Export functionality (study results) not working	This will be implemented
It's easy to forget to fill in some inputs, which may cause errors or not.	Data validation process will be implemented. Input pages will be reorganized to simplify the input process and reduce the likelihood of forgetting.
Not always obvious why some inputs are locked or shaded in complexity 1.	Information will be provided, or locked inputs will be hidden.
We're not sure why site inputs are separate from the rest of the modules.	This will be modified
Data checks to validate if the correct file was introduced (or if any required file or input is missing)	This will be implemented
Unclear error messages	More informative error messages will be implemented

Issue	Resolution
More guidance in the GUI could be provided	This will be implemented
Allow user to visualize and edit other module inputs (instead of just delete)	This will be implemented
Editing the previously introduced inputs is not easy, as editing leads to deleting every single input and starting again	This will be implemented
Button clicks not always registered	Partially due to temporarily slow server. Solved.
Unclear what some inputs mean. - What does the max Hs refer to? Just the towing operation? - What does the safety factors refer to? Just the vessel area? - Vessel statistics was not clear -Clarify what the past experience in MRE means - Not clear what underwater inspection refers to	Information will be added
Cable load-out is not clear	Solved.
OCT/HDD methods could be further described to the user	Information will be added
The system did not respond promptly; the input time was sometimes very long	Partially due to temporarily slow server and a high number of simultaneous users testing the tool. Still, this will be improved.
Provide feedback about the expected computation time	This will be implemented
Bug in the results page, which required refreshing the page to visualize the correct results.	This will be implemented
Introduce units of measurement in the outputs	This will be implemented
Formatting results table and Gantts	This will be implemented

TABLE 4.47: LOW PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF LMO

Issue	Resolution
When not on full screen mode, the buttons become unformatted	We will implement this if there is time.
Json file is hard to use for new users. Running LMO in standalone, it is impossible to assess if the data was correctly provided or if anything was missing	We will implement this if there is time.
Showing logging when running the module would be useful to monitor the calculation steps	We will implement this if there is time.
It would be important to visualise the introduced inputs (possibly on the results page) in order to check what was run.	We will implement this if there is time.
If an input file is too large (e.g. site input), the duration of uploading to the database should be shown to the user	We will implement this if there is time.

Allow the user to specify a specific sequence of tasks to be led onshore and offshore	This has been implemented through the catalogues, which are editable. However, it is currently not user friendly. This will be improved if there is time.
Consider bubble curtain equipment to the piling equipment.	This will be added if there is time.
Allow the user to specify additional equipment that must be transported on deck for the installation and maintenance of the devices.	This can already be partially achieved by increasing the dimensions of the device. This will be added if there is time.
The device dimensions may be further broken down. For the installation, the dimensions must include the support structure. However, when retrieving the device to repair at port (or on deck), the support infrastructure may be left on the seabed. This would lead to deck space savings	In the unlikely event of having time, we will implement this.
Implement additional inspection equipment (namely acoustic system) besides the ROV equipment	In the unlikely event of having time, we will implement this.
Include preventive maintenance operations (inspection) that require removing the device.	This may be partially achieved by editing the maintenance catalogues, but this is currently not user friendly. This will be improved if there is time.
Modify the colours of the "waiting on weather" on the installation and maintenance Gantt charts to red or a more visible colour	We will implement this if there is time.

TABLE 4.48: ISSUES THAT WILL NOT BE IMPLEMENTED IN THE BETA VERSION OF LMO

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.	This has to do with the aspect of the global toolset of the DTOceanPlus suite of tools, and the Consortium will make a decision.
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 the DTOceanPlus suite of tools, and the Consortium will make a decision.
Left hand panel is not intuitive and not always working correctly	This has to do with the aspect of the global toolset of the DTOceanPlus suite of tools, and the Consortium will make a decision.
It seems that the "Delete" button in Site inputs does not work. A message "LMO study with that ID does not have a site yet." pops up when this button is clicked. In addition, if the "Update" button is pressed, the pop-up	This bug was caused by a temporary server freeze due to low memory. Once the server was back on, this problem disappeared.

message is empty and cannot direct the user back to the interface "Project".	
Implement weights to the port selection algorithm in respect to port experience in previous marine energy projects instead of having it as a strict selection criterion.	This will not be implemented as not being a priority.

5. CONCLUSIONS

The objective of Task 5.9 was to carry out the testing of the Deployment Design tools in order to verify that it meets all the previously defined requirements (in WP2 [16] and T5.1 [5]). The verification task has shown that each of the Deployment 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 Deployment Design Tools is now available. Additionally, a first draft of the technical and user manuals delivered alongside the final version of the tools has been written and 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 Deployment 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 Deployment 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.

6. REFERENCES

[1] V. S. Neary, M. Lawson, M. Previsic, A. Copping, K. C. Hallett, A. LaBonte e D. Murray, "Methodology for design and economic analysis of marine energy conversion (MEC) technologies. SANDIA Rerport SAND2014-9040," SANDIA, 2014.

[2] DTOceanPlus, Deliverable 2.1_"Results from user-groups consultation", 2018.

[3] DTOceanPlus, "Deliverable D4.1_Technical requirements for the implementation of a world class Stage Gate Assessment Framework in Ocean Energy," 2019.

[4] WES, "Deliverable D4.2 'Stage Gate tool - Alpha version'," 2020.

[5] DTOceanPlus, "Deliverable D5.1_Technical Requirements for the Deployment Design Tools," 2019.

[6] Hill, C., S. Neary, V., Gunawan, B., Guala, M., Sotiropoulos, F., "U.S. Department of Energy Reference Model Program RM1: Experimental Results," 2014.

[7] M. Topper, S. Olson e J. Roberts, "Techno-Economic Modelling of Tidal Energy Converter Arrays in the Tacoma Narrows," *Journal of Marine Science and Engineering* , vol. 8, nº 9, 2020.

[8] Y. Kervella, "DTOceanPlus Deliverable 5.2 "Site Characterisation – Alpha version"," 2020.

[9] A. Tetu, F. Ferri, V. Nava e D. R. Noble, "DTOceanPlus Deliverable 5.3 "Energy Capture-Alpha version"," 2020.

[10] J. Lopez-Mendia, I. Touzon, E. Robles, J. Lopez-Queija, J. Henderson e F. Ferri, "DTOceanPlus Deliverable 5.4 "Energy Transformation-Alpha version"," 2020.

[11] D. R. Noble e A. Nambiar, "DTOceanPlus Deliverable D5.5 "Energy Delivery tools-Alpha version"," 2020.

[12] N. Luxcey, R. Isorna, N. Germain, V. Nava, I. Tunga e D. R. Noble, "DTOceanPlus Deliverable 5.6 "Station Keeping tools-Alpha version"," 2020.

[13] F. C. d. Fonseca, L. Amaral, M. Rentschler, F. Arede, P. Chainho, Y. Yang, D. R. Noble, A. Petrov, V. Nava, N. Germain, N. Lariviere-Gillet, J. Henderson e B. Hudson, "DTOceanPlus Deliverable 5.7 "Logistics and Marine Operations tools-Alpha version"," 2020.

[14] D. Finlayson, "The Geomorphology of Puget Sound Beaches," Puget Sound Nearshore Partnership / University of Washington, Seatle, 2006.

[15] C. O'Donoghue, M. Topper e D. Bould, "DTOcean / dtocean-database," GitHub, 12 March 2019. [Online]. Available: https://github.com/DTOcean/dtocean-database.

[16] D. R. Noble, A. Nambiar, T. Bloise-Thomaz, H. Jeffrey, V. Nava, F.-. X. Faÿ, P. Ruiz-Minguela, I. Touzon, J. L. Mendia, S. Bradley, N. Eraut, I. Tunga, J. Henderson, J. Hodges, Germain, Nicolas, Spraul, Charles, Safi, Georges, Fonseca, Francisco, Silva, Marta, Ferri, Francesco, Relun, Nicolas e Pons, Frédéric, "DTOceanPlus Deliverable D2.2 Functional requirements and metrics of 2nd generation design tools".

[17] "NetCDF format," [Online]. Available: https://www.unidata.ucar.edu/software/netcdf/.

[18] DTOceanPlus, Deliverable 6.3_"Reliability, Availability, Maintainability and Survivability Assessment Tool - Alpha version", 2020.

[19] DTOceanPlus, "Deliverable D6.1_Technical Requirements for the Assessment Design Tools," 2019.

[20] DTOceanPlus, Deliverable 6.2_"Performance and Energy Yield Tools - Alpha version", 2019.

[21] DTOceanPlus, Deliverable 6.4_"System Lifetime Costs Tools - Alpha version", 2019.

[22] DTOceanPlus, Deliverable 6.5_"Environmental and Social Acceptance Tools - Alpha version", 2020.

[23] V. Nava, I. T. Gonzalez, J. L. Mendia, M. Silva, F. Fonseca, I. Tunga, J. Henderson, J. Hodges, N. Germain, G. Safi, E. Araignous, F. Ferri e Y. Yang, "DTOceanPlus Deliverable 6.1 "Technical Requirements for the Assessment Design Tools"," 2019.

[24] "D5.2 Site Characterisation - Alpha Version," [Online]. Available: https://www.dtoceanplus.eu/content/download/5622/file/DTOceanPlus_D5.2_Site-Characterisation_FEM_20200430_v1.0.pdf..

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[4], 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[5].

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.

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.

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

7.2 SITE CHARACTERISATION (SC)

This document is the User manual for the Site Characterisation module within the DTOceanPlus suite of tools.

- For new Users, the tutorials give step-by-step instructions on how to use the module:
  - Accessing the module on the Open cascade server,
  - Creating a new study in standalone mode,
  - Using the module at low, medium and high complexity levels.
- 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.

Using environmental data of a study site, the Site Characterisation (SC) module gives the User the main characteristics of this site in terms of bathymetry, seabed types, marine species, waves, tidal currents, winds and water levels. It also includes a time series of pertinent parameters as well as statistics on these parameters like probability distributions, scatter diagrams or extreme values.

7.2.1 Overview of the SC Functionalities

SC tool provides databases extraction feature and computes statistics based on these extractions. These two main features of the module are described in the following sections. For more details about these functionalities, please refer to the technical note of the SC module [8].

For consistency with the other tools, the module works with three different complexity levels, which reflect the level of information that the User needs to provide. The module produces the same outputs in terms of computed statistics. However, 2D Maps may not be generated depending on the input data.

At the early[1] complexity level, named "level 1" in the GUI, punctual databases are proposed to the user who defines the wanted levels of energy for waves and tidal currents. The bathymetry is automatically defined using the databases included in the module except if the User wants a constant depth which would be required then. The outputs are timeseries of main parameters as well as statistics but do not include 2D Maps as the databases are punctual.

At the mid[2] complexity level, named "level 2" in the GUI, 2D databases are proposed to the User who, same as the low complexity level, needs to define the levels of energy for waves and tidal currents. The outputs would then also include the computed statistics and 2D Maps of bathymetry, seabed type, currents magnitude and waves significant height.

At the late complexity level, the SC module allows the user to import their databases for the lease area, corridor, seabed type and associated roughness length, endangered species, time series (for example, the significant wave height or the tidal current magnitude) and the bathymetry. These databases are extracted, and statistics are computed. Statistics, timeseries of the main parameters and 2D maps (if the inputs are in 2D) are finally provided to the User.

7.2.1.1 Databases extraction

For low and medium complexity levels, default databases would be used for this extraction, while for high complexity level (level 3), the User chooses and import their databases. Considering this distinction, the following list resumes the different data extracted by the module:

- The water depth between the bottom and the local mean sea level expressed as "m from MSL" (Mean Sea Level)
- The type of sediment (rocks, pebbles, sands, ...)
- From the type of sediment database, the roughness length z_0 is computed using Nikuradse's formula, which says that the gross roughness is equal to 2.5 times the average diameter (D50) of the sediment. z_0 is expressed in meters.
- The probability of the presence of endangered species. In the default database, 26 species were listed following the international and European conventions. This probability of presence is expressed in %.
- Timeseries are also extracted from the databases for each complexity levels (at one point for complexity level 1, at several points for complexity level 2 and at one or several points for complexity level 3 depending on the User input databases). The following databases are extracted:
    a. Waves: significant wave height (Hs, in m), wave peak period (Tp, in s), wave peak direction (Dp, in °, "coming from" convention), wave energy period (Tom1 or Te, in s), wave energy flux (CgE, in kW/m);
    b. Tidal currents zonal and meridional component (Ucur, in m/s, Vcur, in m/s);
    c. 10m-wind speed zonal and meridional components (Uwnd, in m/s, Vwnd, in m/s);
    d. Water levels fluctuations (Wlev, in m).

7.2.1.2 Statistics

For each variable extracted from the databases, a list of statistics is computed, from basic ones to multivariate extreme values analysis.

- The *mean* is the average value of the timeseries, *i.e.* the sum of individual values over time divided by the number of individual values.
- The *min* and *max* are, respectively, the lowest and the highest individual values of the timeseries.
- The *median* is a simple measure of central tendency. To find the median, the individual values are arranged from the smallest to the largest value. If there is an odd number of observations, the median is the middle value. If there is an even number of observations, the median is the average of the two middle values.

- The standard deviation std is a numerical value used to indicate how widely individuals in a group vary. If individual values vary greatly from the group mean, the standard deviation is big, and vice versa.
- EPD (Empirical Probability Distribution) represents the distribution of the variable directly extracted from the database. It shows the percentage of occurrence of the variable inside a range of bins.
- EJPD (Empirical Joint Probability Distribution) represents the distribution of two variables considered together. It shows the percentage of occurrence inside bins.
- This statistic computes the wave environments Hs/Dp in order to calculate the fatigue analysis in the module Station Keeping of the DTOcean+ suite. It uses the statistic EJPD to jointly cut Hs and Tp by bins and then classifies the results from the most probable environment to the less probable one. It also associates to each of these environments the mean wave peak period (Tp), the maximum current speed and its associated current direction, the maximum wind speed and its associated wind direction. More information is available in "D6.2 Station Keeping Tools".
- EXT (EXTreme) statistic is based on an Extreme values analysis. It uses probabilistic laws to predict extreme events (also called extreme values, or return values) for a particular phenomenon over large return periods that usually exceed the duration of the measured or modelled data.
- EXC (Extreme Contours) is the statistics extreme contours, also known as environmental contour, this statistic represents a rational procedure for defining an extreme sea stat condition. The objective is to define contours in the environmental parameter space along which extreme responses with a given return period should lie (Winterstein et al., 1993) (DNV-RP-C205, 3.7.2).

7.2.2 Workflow for using the SC module

The workflow for using the Site Characterisation 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 7.1.

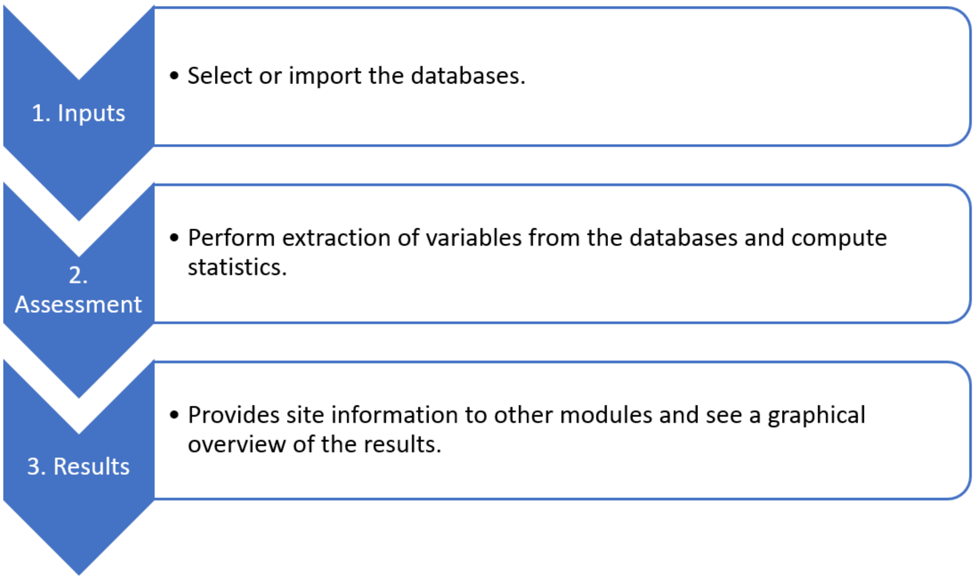


FIGURE 7.1: THE WORKFLOW FOR USING THE SITE CHARACTERISATION MODULE

7.2.3 Overview of SC data requirements

This section summarises the types of input data required to run the Site Characterisation module. Full details and data specifications are given in section 3.1.4. The required inputs to run the module are summarised in Table 7.1.

TABLE 7.1: SUMMARY OF REQUIRED INPUTS

Section	Complexity 1	Complexity 2	Complexity 3
Waves	Level of energy	Level of energy	Time series of all variables described in section 1.1.1
Tidal current	Level of energy	Level of energy	Time series of all variables described in section 1.1.1
Bathymetry	None or a constant value	None or a constant value	Constant value or a Netcdf file
Lease Area	None	None	Shapefile of the lease area
Corridor	None	None	Shapefile of the Corridor
Seabed Type	None	None	Netcdf file
Roughness Length	None	None	Netcdf file. Expressed as z_0 in *m*
Species	None	None	Netcdf file. Expressed as %

7.2.4 SC Tutorials

7.2.4.1 Accessing the Site Characterisation module on the Open Cascade server

The Site Characterisation module has been hosted on the Open Cascade server for the verification tasks. To access the module, visit the web link and log into the server using the provided Username and password.

7.2.4.2 Creating a new Site Characterisation study in standalone mode

Once logged into the server, the next step is to create a new study within the Site Characterisation 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. On the home page, click on the 'Site Characterisation' image and click on 'Create new project'.
2. Choose "Standalone" running mode, then select the appropriate complexity level.
3. The list of the required inputs will then appear on the following page
4. From this page, 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.*]

7.2.4.3 Using Site Characterisation at low and medium complexity level in standalone mode

If no study site is selected or no databases are available to import into the model, use the low and medium complexity level of the Site Characterisation module.

1. If required, create a new complexity level 1 or 2 study, as described in section 1.2.4.2.
2. Select the requested level of energy for the wave and current between low, medium and high
3. Choose if a uniform bathymetry is required for the study
   a. If not, the default database will be used
   b. If it is required, enter the water depth in meters
4. Click on "Run Module" to launch the computation
   a. If it has not already been done, enter a name for your project in the "Save your inputs before running" pop up
   b. Click on "Save" to save your project under the indicated name
5. You can follow the progress of your project in the log section.
6. If the project is successful, click on the "See Results" button to access the first results page ", Overview."
7. On the sidebar (on the left of the window), click on Waves, currents or 2D Maps to navigate these pages.

8. (Optional) Click on "Export results to PDF" to export all results pages in a single PDF document

7.2.4.4 Using Site Characterisation at high complexity level in standalone mode

To perform a calculation on a given site using default or imported databases, use the full complexity (level 3) version of the Site Characterisation module.

1. If required, create a new complexity level 3 study, as described in section 1.2.4.2.
2. Select a default example in the list or select "Import"
   a. If "Import" is selected for the lease/corridor field, select a shapefile to import. The other required files (.shx, .prj, .dbf) will be extrapolated from the shapefile by the module.
   b. If "Import" is selected for the Seabed Type, the Roughness Length or the Species fields, select a Netcdf file to import. The required construction of these files are detailed in the technical note.
   c. If "Import" is selected for the Timeseries field, select a Netcdf file or a .csv file to import. The construction of these files is detailed in "How to" note.
3. Choose if a uniform bathymetry is required for the study
   a. If not, select a default example or "Import" to import a Netcdf file describing the bathymetry.
   b. If it is required, enter the water depth in meters
4. Click on "Run Module" to launch the calculation
   a. If it has not already been done, enter a name for your project in the "Save your inputs before running" pop up
   b. Click on "Save" to save your project under the indicated name
5. You can follow the progress of your project in the log section.
6. If the calculation is successful, click on the "See Results" button to access to the first results page "Overview"
7. On the sidebar (on the left of the window), click on Waves, currents or 2D Maps to navigate these pages.
8. (Optional) Click on "Export results to PDF" to export all results pages in a single PDF document

7.2.5 SC How-to Guides

7.2.5.1 How to prepare data using the Site Characterisation module

For complexity level 3, the User can enter their own files. If they do not have all the necessary input files for the SC module, they will also be able to use the DTOceanPlus databases of the previous two levels of complexity. In order to use their own data, the User must respect certain formats, which are described below.

Direct values formats (Bathymetry, seabed properties, species):

- Direct values databases must be in NetCDF format [17]
- Files are a structured matrix whose dimensions are longitude and latitude. Examples can be found in the Databases folder of the module.
- Possible names for the longitude variable are: 'longitude', 'lon', 'x' or 'X'.
- Possible names for the latitude variable are: 'latitude', 'lat', 'y' or 'Y'.
- Possible names for the bathymetry variable are: 'Ho', 'Band1', 'elevation', 'Bathymetry', 'DEPTH' or 'depth'. Convention is positive values in the ocean, referenced to the mean sea level.
- Possible names for the seabed type variable are: 'seabed_type' or 'sediment_type'.
- Possible name for the roughness length variable is: 'roughness_length'.
- User inputs in terms of endangered species are possible via the ESA tool graphical User interface.

Timeseries (waves, tidal currents, winds and water levels):

Temporal databases must be either in NetCDF format or in csv format

For the NetCDF format, the file must contain all variables and dimensions: time,longitude, and latitude.

For the csv, the delimiter is the character "," and all the variables must be in the same file.

For 1D timeseries, needed variables are the following (if a variable is missing, fill the column with zero "0"): 'hs' (significant wave height), 'tom1' (wave energy period), 'spr' (wave directional spreading), 'fp' (wave peak frequency), 'dp' (wave peak direction), 'cge' (wave energy flux), 'wlv' (water level fluctuation), 'ucur' (zonal component of tidal current), 'vcur' (meridional component of tidal current), 'uwnd' (zonal component of 10m-wind), 'vwnd' (meridional component of 10m-wind).

Figure 7.2 shows an example of csv file that can be used in the SC module (1D timeseries).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	times	longitude	latitude	hs	t0m1	spr	fp	dp	cge	wlv	ucur	vcur	uwnd	vwnd
2	01/01/2015 00:00	-1.691	48.6761	0.27	6.76	55.8	0.079	313.0	0.2	0.0	0.22	-0.2	0.0	5.9
3	01/01/2015 01:00	-1.691	48.6761	0.294	5.87	59.3	0.082	312.0	0.2	1.44	0.19	-0.2	-0.2	6.4
4	01/01/2015 02:00	-1.691	48.6761	0.31	5.6	61.3	0.083	312.0	0.3	2.65	0.11	-0.15	-0.2	6.8
5	01/01/2015 03:00	-1.691	48.6761	0.312	5.73	60.5	0.084	312.0	0.3	3.23	0.01	-0.06	0.2	6.7
6	01/01/2015 04:00	-1.691	48.6761	0.308	5.74	59.4	0.086	313.0	0.3	3.02	-0.1	0.04	0.1	6.4

FIGURE 7.2: EXAMPLE OF CSV FILE FOR 1D TIMESERIES

For 2D timeseries, needed variables are the following (if a variable is missing, fill the column with zero "0"): 'hs' (significant wave height), 'fp' (wave peak frequency), 'dp' (wave peak direction), 'wlv' (water level fluctuation), 'ucur' (a zonal component of tidal current), 'vcur' (meridional component of tidal current).

Figure 7.3 shows an example of CSV file that can be used in the SC module (2D timeseries), which indicates that all the points (couple of longitude/latitude) must be specified at each time.

times	longitude	latitude	hs	fp	dp	wlv	ucur	vcur
01/01/2015 00:00	-1.691	48.6761	0.27	0.079	313.0	0.0	0.22	-0.2
01/01/2015 00:00	-1.6914	48.674	0.294	0.082	312.0	1.44	0.19	-0.2
01/01/2015 00:00	-1.6899	48.6718	0.31	0.083	312.0	2.65	0.11	-0.15
01/01/2015 00:00	-1.6932	48.6777	0.312	0.084	312.0	3.23	0.01	-0.06
01/01/2015 00:00	-1.6877	48.6763	0.308	0.086	313.0	3.02	-0.1	0.04
01/01/2015 00:00	-1.6946	48.6754	0.308	0.086	313.0	2.07	-0.18	0.13
01/01/2015 00:00	-1.6896	48.6785	0.282	0.086	314.0	0.6	-0.22	0.19
01/01/2015 00:00	-1.6943	48.6729	0.29	0.087	314.0	0.0	-0.21	0.21
01/01/2015 00:00	-1.6933	48.6707	0.306	0.087	315.0	0.0	-0.14	0.17
01/01/2015 00:00	-1.6866	48.6727	0.314	0.089	315.0	0.0	-0.04	0.09
01/01/2015 00:00	-1.6898	48.6694	0.334	0.09	315.0	0.0	0.07	-0.01
01/01/2015 00:00	-1.6945	48.6798	0.366	0.093	314.0	0.0	0.17	-0.11
01/01/2015 00:00	-1.6858	48.6781	0.404	0.096	312.0	0.0	0.22	-0.19
01/01/2015 00:00	-1.6974	48.6736	0.442	0.098	311.0	0.61	0.23	-0.22
01/01/2015 00:00	-1.6869	48.6802	0.464	0.1	310.0	2.17	0.17	-0.19
01/01/2015 00:00	-1.6965	48.6713	0.46	0.102	310.0	3.2	0.07	-0.12
01/01/2015 00:00	-1.6924	48.6816	0.452	0.104	311.0	3.46	-0.04	-0.02

FIGURE 7.3: EXAMPLE OF CSV FILE FOR 2D TIMESERIES

7.3 MACHINE CHARACTERISATION (MC)

This is the User Manual for the Machine Characterisation module within the DTOceanPlus suite of tools.

- For new Users, the tutorials give step-by-step instructions on using the tool,
- 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 Machine Characterization module is used to define the features of either a Tidal or Wave energy device that can be later used in the other modules of the DTOceanPlus suite of the tool. The module can be assimilated to a catalogue with special functionality; in the case of wave energy converter at high complexity, the module is used to estimate the hydrodynamic coefficients of the system.

It is one of the Deployment Design tools intended to be run at the beginning of the design process.

7.3.1 Overview of the MC Functionalities

The main purpose of the Machine Characterisation module is to collect data used to describe the machine functionality, dimensions, cost, etc.... The inputs are divided into three main categories:

- General – collect information such as Unit Cost, Mass, Materials, Connector and Foundation types
- Dimensions – collect information of sizes, areas and volumes
- Model – collect information that characterises the power performance of the machine, efficiency, number of generators, etc....

Given the exception of the case of wave energy converters at high complexity, the outputs of the module are exactly the inputs given by the User.

For the special case of wave energy converters at high complexity, the module outputs are the hydrodynamic coefficients and the matrices required by the Energy Capture module to estimate the hydrodynamic interaction between devices in the array.

The module can either be run in three levels of complexity low (complexity 1), medium (complexity 2) and high (complexity 3). The higher the complexity, the higher the number of inputs required by the system.

7.3.2 Workflow for using the MC module

The workflow for using the Machine Characterisation module can is summarised in the graph below:

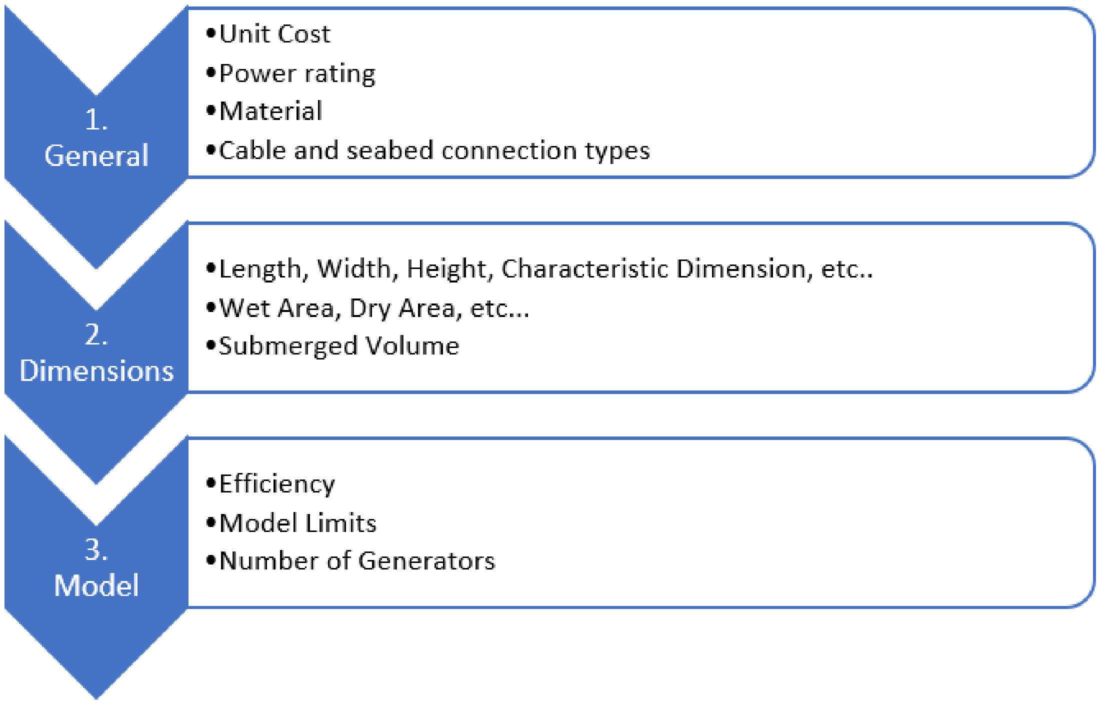


FIGURE 7.4: THE WORKFLOW FOR USING THE MACHINE CHARACTERISATION MODULE

For the special case of wave energy converters at high complexity, the step three can be further divided into three sub-steps:

1. Input definition
2. Coefficients calculation
3. Output visualization

7.3.3 Overview of MC data requirements

This section summarises the types of input data required to complete the Machine Characterization module. Full details and data specifications are given in the how-to guide on preparing data.

Since this the main module functionality is to collect data for the other modules, all the inputs presented to the User in the GUI are required. Some of the parameters will be masked in the GUI depending on the complexity level. Contrary to other design modules that consume and provide data, the Machine Characterization module is a data provider; therefore, the module has the exact same behaviour both in the standalone and in the integrated mode.

TABLE 7.2: SUMMARY OF REQUIRED INPUTS

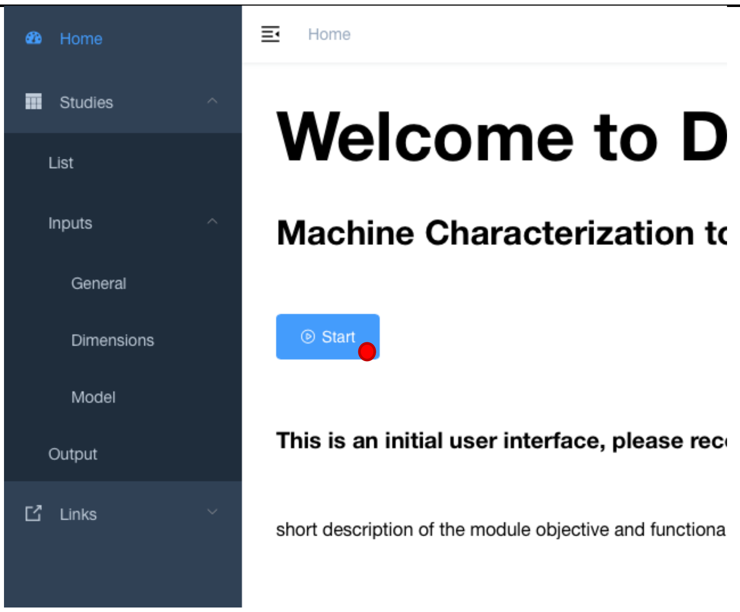
Section	Description
General	▫ Unit Cost ▫ Power Rating ▫ Material ▫ Mass ▫ Footprint ▫ Electrical connection type ▫ Foundation type ▫ Device technology: fixed/floating ▫ Etc …
Dimensions	▫ Characteristic Dimension (rotor diameter or characteristic length) ▫ Overall machine size ▫ Wet and Dry areas ▫ Volumes ▫ Etc …
Model	▫ Efficiency (power coefficient or capture width ratio) ▫ Limits ▫ Machine functionality

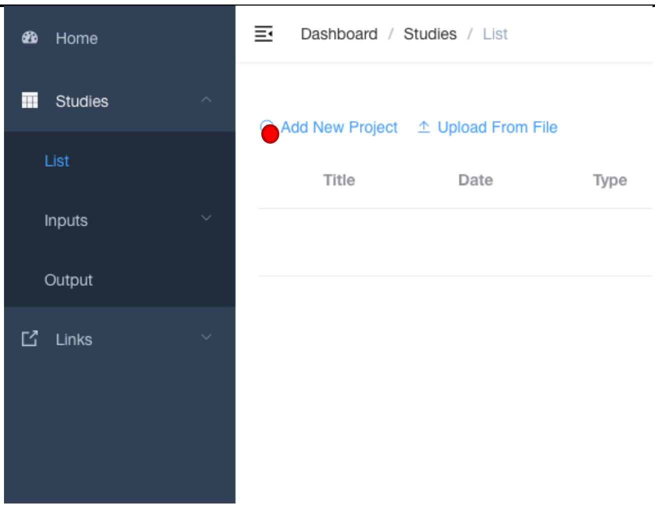
7.3.4 MC Tutorials

It is important to notice that the information contained in this section refers to the actual state of development of the module, which might vary if compared to the released version due to the feedback gathered by the Users in verification and validation tasks.

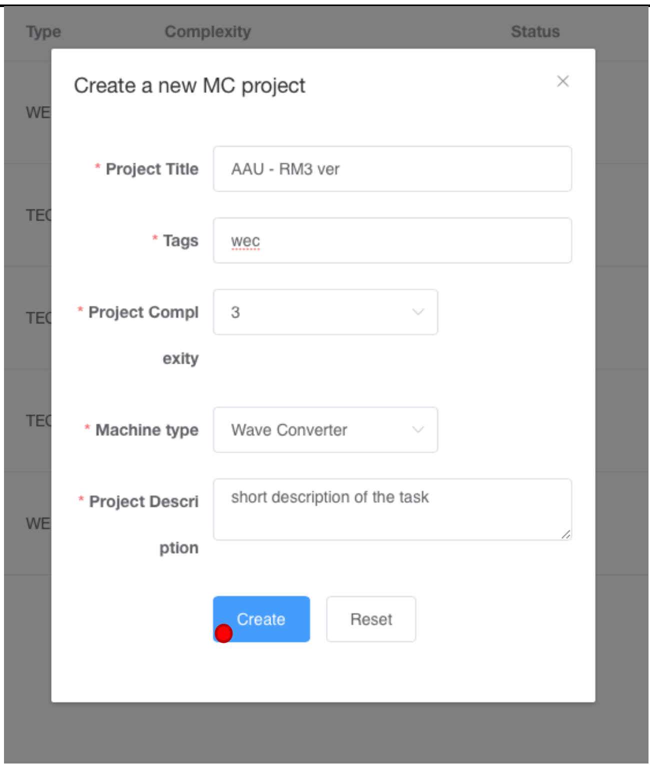
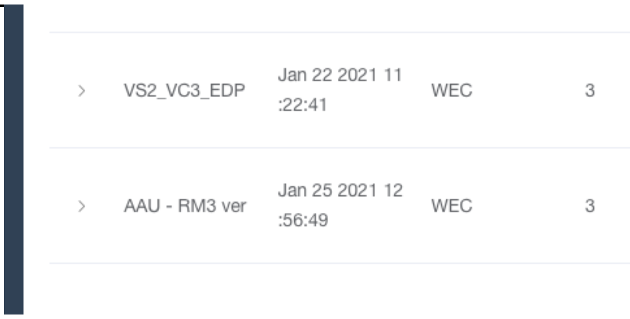
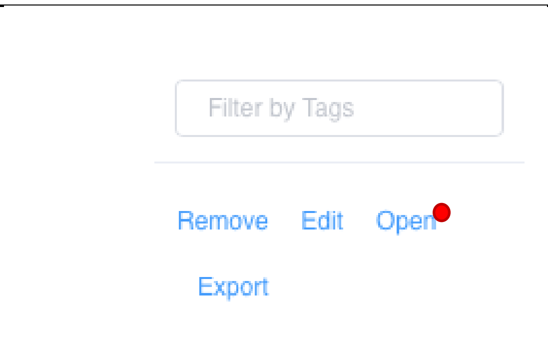
7.3.4.1 Creating a new Machine Characterization study in standalone mode

Once logged into the server, the next step is to create a new study within the Machine Characterisation 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.

<table>
<tr>
<td>


</td>
<td>Click on the start button to visit the list of available projects.</td>
</tr>
<tr>
<td>


</td>
<td>Click on the "Add New Project" to add a project.</td>
</tr>
</table>

	Fill the form based on the verification case to run. It is important to select the correct Machine Type and Project complexity. Click on the "Create" button to create the project.
	The project will appear in the Table in the middle of the screen. Use the scroll bar on the right-hand side of the screen if the project is not visible.
	To open the project page, click on the "Open" button on the right-hand side of the table.

7.3.4.2 Using Machine Characterisation

In the general case, after a study has been created, the user is guided to defining the three types of input previously described. For each of the input, the process is similar:

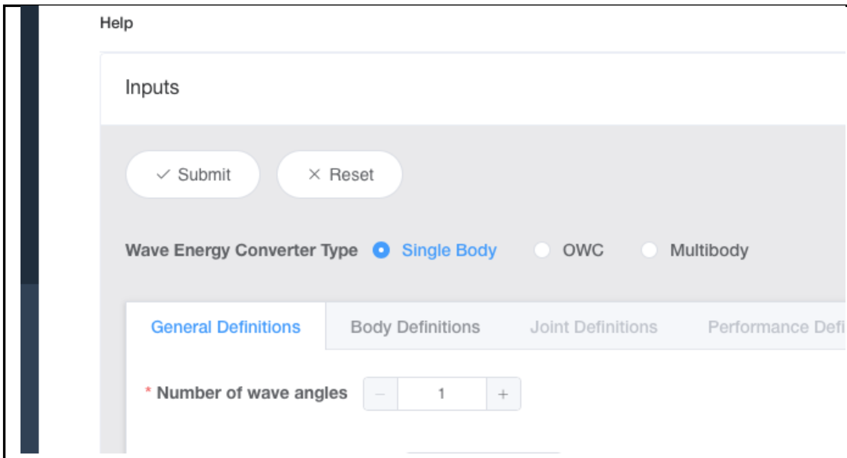
1) Fill the input in the given form
2) Save the inputs into the DB using the "Submit" button
3) Move to the next section

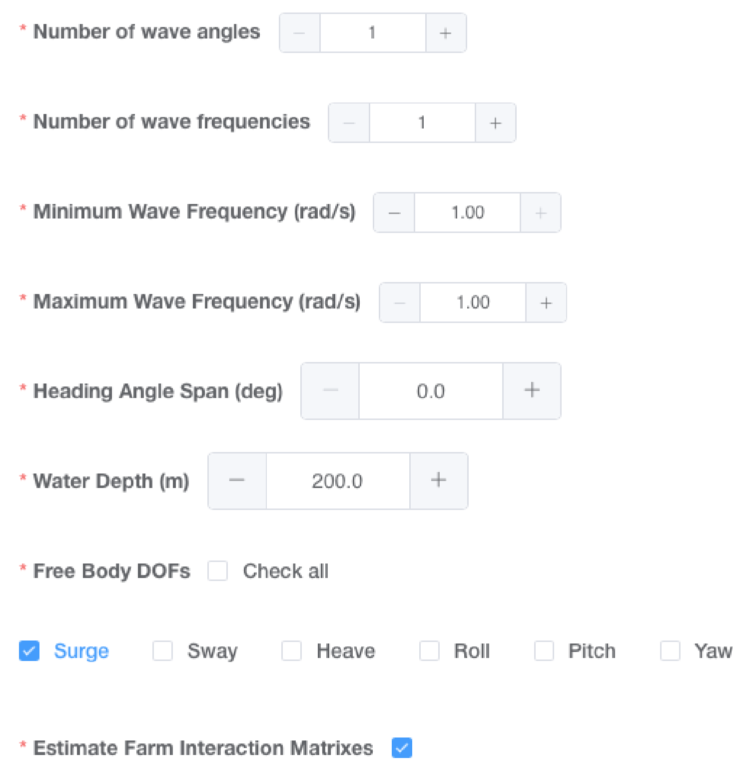
Please note that the data is not automatically saved, but it is the User's responsibility to click the "Submit" button.

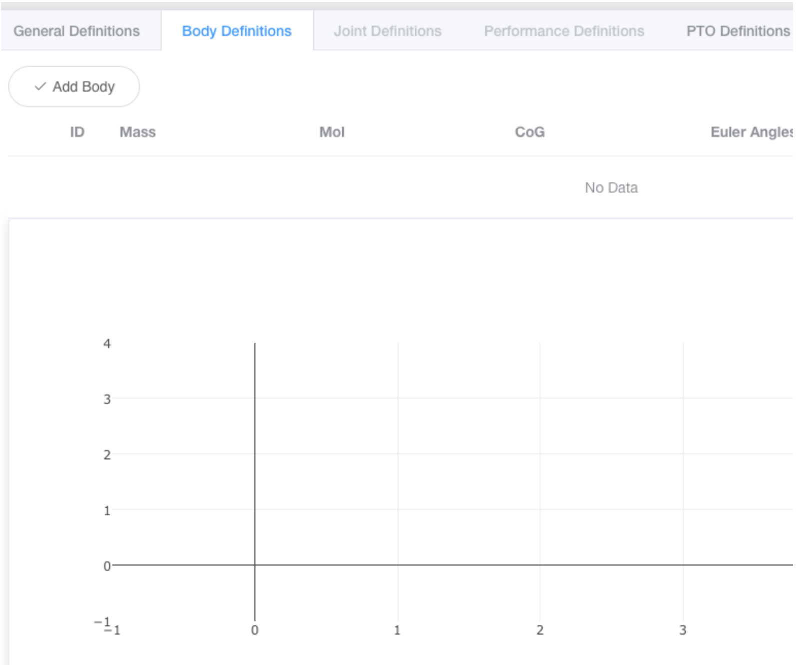
The three sections of the inputs can be filled in any order.

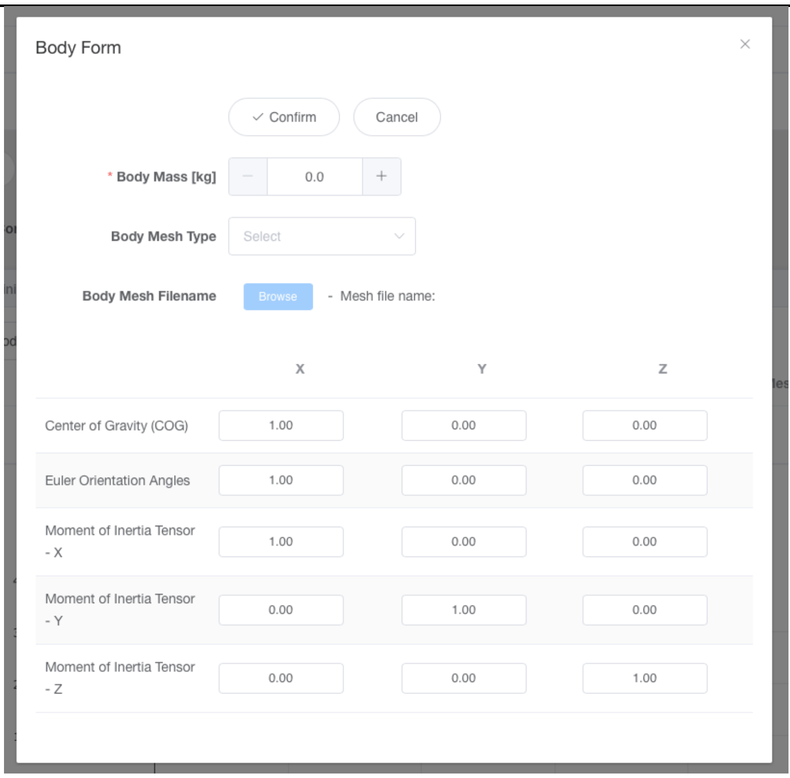
7.3.4.2.1.1 WAVE ENERGY CONVERTER AT COMPLEXITY 3

For the case of a wave energy converter at complexity 3, the General and Dimensions inputs remain unchanged, while the model input requires the additional calculation and output visualization steps.

	Select the type of machine. OWC requires the User to provide the mesh file of the water column inside the chamber. Multibody represents a single WEC unit composed of several bodies, mechanical interconnected. For example, RM3 or Pelamis are examples of Multibody WECs

	Specify the general model inputs: 1) Number of wave angles used to discretize the numerical model 2) Number of wave frequency used to discretize the numerical model 3) Heading Angle Span represent the capability of the converter to orient itself with the incoming wave direction. 0deg -> the device cannot rotate. 360deg-> the device will always rotate toward the incoming wave direction 4) Free Body DOFs represents the overall DOF of the body. A fully unconstrained system will have all the DOF checked. For Multibody system the DOF associated to the mechanical constraints are defined in the Joint Tab. 5) Estimate Farm Interaction Matrix MUST be checked if the Energy Capture module must be run after.

<table>
<tr>
<td>
</td>
<td>Click on the Body Definition Tab to define the geometry properties of the machine.

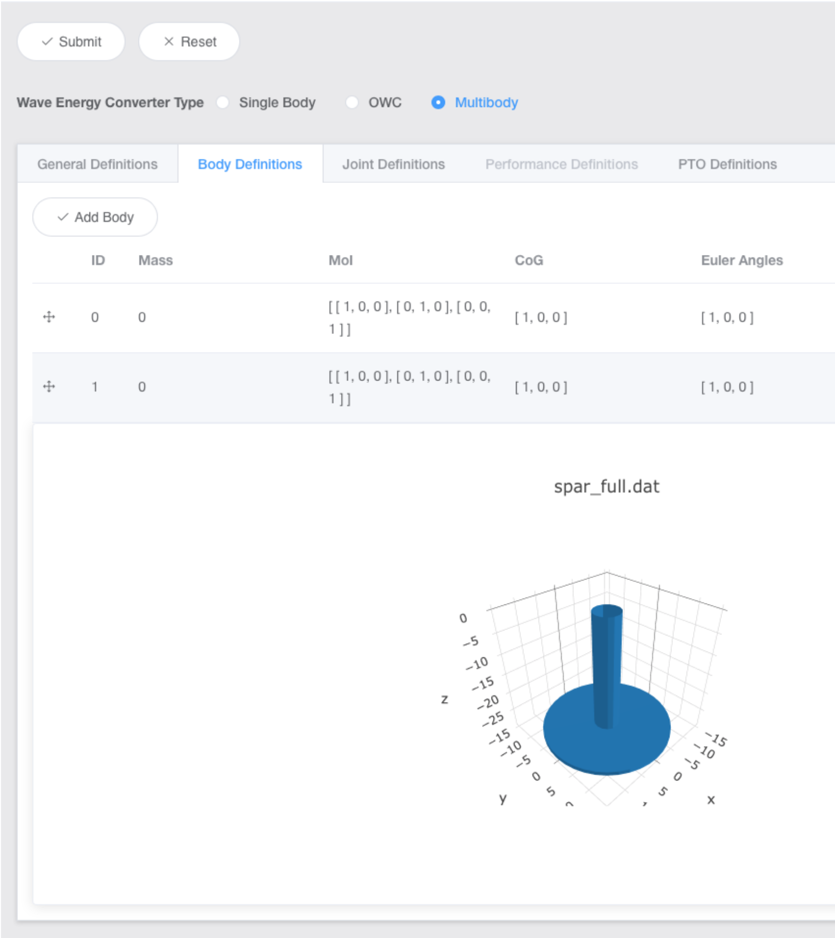
To add a Body click on Add Body.</td>
</tr>
<tr>
<td>
</td>
<td>Specify all the inputs of the form to fully define the body.

To select a mesh file please first select the mesh type from the list, (only Nemoh available)

Refer to the following page for a description of the mesh file format.

https://lheea.ec-nantes.fr/valorisation/logiciels-et-brevets/nemoh-mesh

Click Confirm to add the body.</td>
</tr>
</table>



The body will be listed in the Body Table. You can delete the body or visualize the associated mesh using the icons on the Operation column.

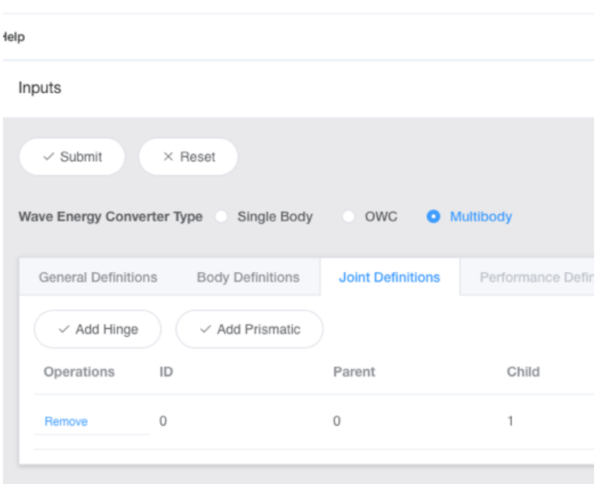
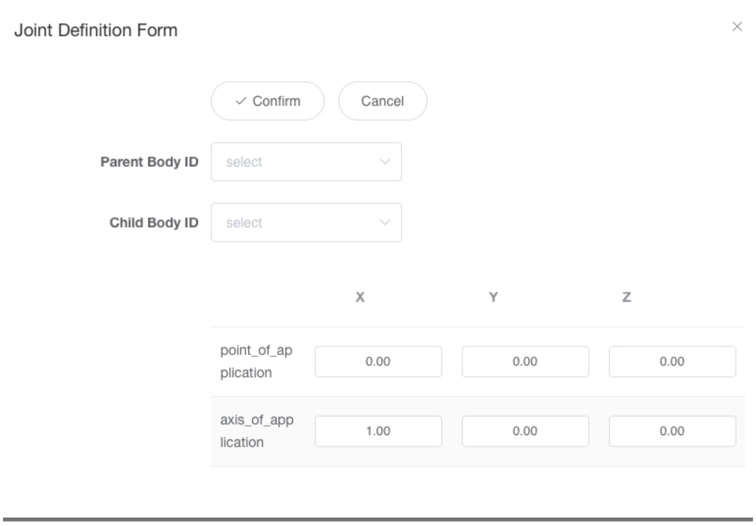
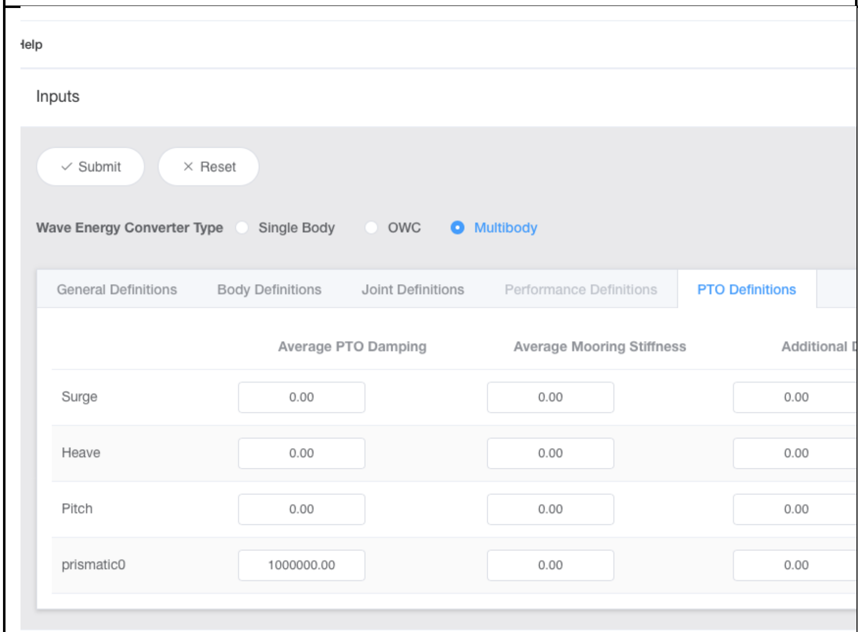
If Single Body is selected, you cannot add any other body to the system. Please move to the PTO definition page.

If the OWC is selected, you must provide a mesh of the water column inside the chamber. Click add new body.

If Mulbtibody is selected, you must add all the body to the list following the instructions.

Please be sure that the platform body is always at the top of the list by dragging the rows to the correct position.

The wec platform represent the part of the WEC connected to the mooring or the reference body. In the RM3 the spar must be selected as platform.

	In the Joints Definition tab it is possible to define the mechanical constraints of the Multibody system. Click the corresponding button to add a Prismatic (linear) or a Revolute (rotation) joint.
	Fill the Joints form and click confirm to add the Joint to the list.
	In the PTO Definitions tab is possible to specify the PTO damping, the mooring stiffness and the additional damping and stiffness for each DOF of the machine, including the ones defined in the Joints table.

7.3.5 MC How-to Guides

7.3.5.1 How to prepare data for using the Machine Characterization module

The inputs required to run the Machine Characterization module are mostly single value items, such as integer, float, string and boolean.

In a few specific cases, the User is required to prepare a separate file to be uploaded into the GUI.

The requirements to prepare those files is described in the following (the cases described are just the ones that require the preparation of a file before start, which is not the case for Tidal - complexity medium). For completeness, the full set of data required to run both tidal and wave cases at all complexity levels is given in the following tables.

TIDAL – COMPLEXITY HIGH
For the case of a tidal machine at high complexity, the Power and Thrust coefficients curves can be entered manually, editing the values point by point, or the User can create a simple Excel file, with the data stored in column format. The file must have the following headers respectively in the first row at column A, B and C: velocity, cp, ct. The respective data can be filled from row 2 downwards.

WAVE – COMPLEXITY MEDIUM
For the case of a wave machine at medium complexity, the Capture Width Ratio (CWR) matrix should be provided by the User using a simple excel file, with the data stored in column format. The file must have the following headers respectively in the first row at column A, B, C and D: Hs, Tp, Dir and CWR. The respective data can be filled from row 2 downwards. Since the CWR is a 3D matrix with axis Hs, Tp and Dir, it is important to provide a flattened representation.

WAVE – COMPLEXITY HIGH
For the case of a wave machine at high complexity, the User must provide to files the Capture Width Ratio (CWR) matrix and the body mesh. The first file has been described in the section above.

The mesh file is a discrete representation of the shell of the machine's wetted surface. So far, the only accepted format is the Nemoh format, which description can be found at https://lheea.ec-nantes.fr/valorisation/logiciels-et-brevets/nemoh-mesh. In the final release, other formats will be available such as WAMIT and possibly more general .stl files.

ALL OTHER CASES
For the case of a tidal machine at high complexity, the Power and Thrust coefficients curves can be entered manually, editing the values point by point, or the User can create a simple Excel file, with the data stored in column format. The file must have the following headers respectively in the first row at column A, B and C: velocity, cp, ct. The respective data can be filled from row 2 downwards.

TABLE 7.3: TIDAL GENERAL INPUTS

Inputs description	Variable Name	Complexity	Value	Units
Connector Type	connector_type	all	"wet"	-
Floating Machine	Floating	all	false	Bool
Rated Capacity	rated_capacity	all	1100	kW
Constant Power Factor	constant_power_factor	all	0.0	-
Machine Unit Cost	machine_cost	all	1.960.000	EUR
Material Name	materials.material_name	all	"undefined"	-
Material Quantity	materials.material_quantity	all	219370	kg
Max Installation Depth	max_installation_water_depth	all	-45	m
Min Installation Depth	min_installation_water_depth	all	-67.5	m
Min Interdistance X direction (rotation axis)	min_interdistance_x	all	50.0	m
Min Interdistance Y direction (perperndicular to rotation axis)	min_interdistance_y	all	50.0	m
Target Fundation Type	preferred_fundation_type	all	"pile"	-
Rated Voltage	rated_voltage	all	11.000	V

TABLE 7.4: TIDAL DIMENSION INPUTS

Inputs description	Variable Name	Complexity	Value	Units
Beam Wet Area	beam_wet_area	3	330.0	m²
Rotor Diameter	characteristic_dimension	all	20.0	m
Draft	"draft": 0.0,	all	0.0	m
Dry frontal area	dry_frontal_area	3	0	m²
Dry profile	dry_profile	all	-	-
Footprint Radius	footprint_radius	all	20	m
Total Height	Height	all	30	m
Hub heigth	hub_heigth	3	30.0	m
Total Length	length	all	3.5	m
Total Mass	mass	all	219370.0	kg
Submerged volume	submerged_volume	all	433.0	m³
Wet Area	wet_area	all	-	m²
Wet Frontal Area	wet_frontal_area	3	165.0	m²
Wet Profile	wet_profile	all	-	-
Total Width	Width	all	3.5	m

TABLE 7.5: TIDAL MODEL COMPLEXITY 1

Inputs description	Variable Name	Value	Units
Power Coefficient	cp	0.37	-
Number of Rotor	number_rotor	2	-

TABLE 7.6: TIDAL MODEL COMPLEXITY 2

Inputs description	Variable Name	Value	Units
Power Coefficient	cp	0.37	-
Trust Coefficient	ct	0.43	-
Cut-in Velocity	cut_in_velocity	0.5	m/s
Cut-out Velocity	cut_out_velocity	3	m/s
Number of Rotor	number_rotor	2	-
Rotor Horizontal Interdistance (direction perpendicular to the rotation axis)	rotor_interdistance	10	m

TABLE 7.7: TIDAL MODEL COMPLEXITY 3

Inputs description	Variable Name	Value	Units
Power Coefficient	cp	See Table 3.10	-
Trust Coefficient	ct	See Table 3.10	-
Power and Trust Curves' Velocity	cp_ct_velocity	See Table 3.10	m
Cut-in Velocity	cut_in_velocity	0.5	m/s
Cut-out Velocity	cut_out_velocity	3	m/s
Number of Rotor	number_rotor	2	-
Rotor Horizontal Interdistance (direction perpendicular to the rotation axis)	rotor_interdistance	10	m

TABLE 7.8: TIDAL CP/CT CURVES*

Velocity	Cp	Ct
0.5	0.025	0.024
1	0.621	0.502
1.5	0.558	0.464
2	0.489	0.419
2.5	0.233	0.219
3	0.131	0.127

* only a subset of the data is presented; the full dataset can be found in the verification data and in Figure 7.5.

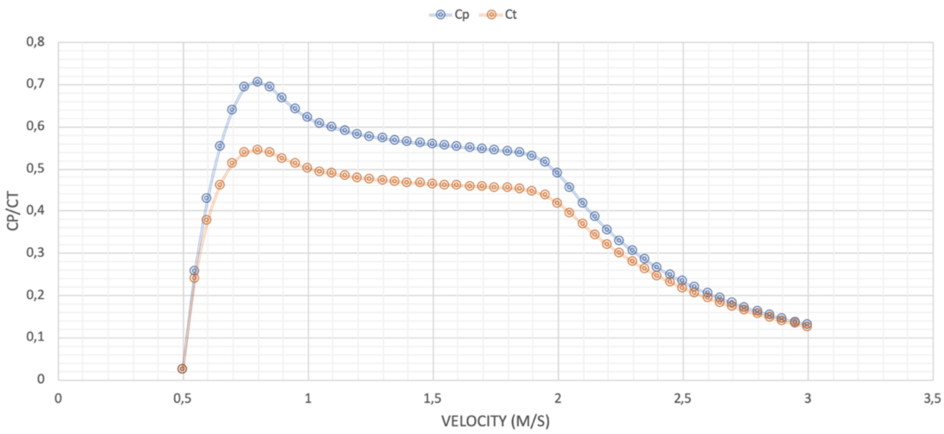


FIGURE 7.5: CP/CT CURVES

TABLE 7.9: WAVE GENERAL INPUTS

Inputs description	Variable Name	Complexity	Value	Units
Connector Type	connector_type	all	"wet"	-
Floating Machine	floating	all	true	Bool
Rated Capacity	rated_capacity	all	286.0	kW
Constant Power Factor	constant_power_factor	all	1.0	-
Machine Unit Cost	machine_cost	all	2.000.000	EUR
Material Name	materials.material_name	all	"undefined"	-
Material Quantity	materials.material_quantity	all	1000000	kg
Max Installation Depth	max_installation_water_depth	all	-40	m
Min Installation Depth	min_installation_water_depth	all	-100	m
Min Interdistance X direction (rotation axis)	min_interdistance_x	all	600	m
Min Interdistance Y direction (perperndicular to rotation axis)	min_interdistance_y	all	600	m
Target Fundation Type	preferred_fundation_type	all	"drag_embedded"	-
Rated Voltage	rated_voltage	all	11.000	V

TABLE 7.10: WAVE DIMENSION INPUTS

Inputs description	Variable Name	Complexity	Value	Units
Beam Wet Area	beam_wet_area	3	-	m²
Characterisitc Dimension	characteristic_dimension	all	6.0	m
Draft	"draft": 0.0,	all	0.0	m
Dry frontal area	dry_frontal_area	3	0	m²
Dry profile	dry_profile	all	-	-
Footprint Radius	footprint_radius	all	20	m
Total Height	height	all	42	m
Hub heigth	hub_heigth	none	-	m
Total Length	length	all	6.0	m
Total Mass	mass	all	1000000.0	kg
Submerged volume	submerged_volume	all	1000.0	m³
Wet Area	wet_area	all	-	m²
Wet Frontal Area	wet_frontal_area	3	-	m²
Wet Profile	wet_profile	all	-	-
Total Width	width	all	6.0	m

TABLE 7.11: WAVE MODEL COMPLEXITY 1

Inputs description	Variable Name	Value	Units
Capture Width Ratio (CWR)	capture_width_ratio	0.31	-
Machine Archetype	machine_archetype	"point_absorber"	-

TABLE 7.12: WAVE MODEL COMPLEXITY 2

Inputs description	Variable Name	Value	Units
Capture Width Ratio (CWR)	capture_width_ratio	see Table 3.19	-
Hs (CWR)	hs_capture_width	see Table 3.19	M

Inputs description	Variable Name	Value	Units
Tp (CWR)	tp_capture_width	see Table 3.19	s
Wave Direction (CWR)	wave_angle_capture_width	0	deg
Machine Archetype	machine_archetype	“point_absorber”	-
Power-Take-Off Average Damping	pto_damping	1000000	N/(m/s)

TABLE 7.13: WAVE MODEL COMPLEXITY 3

Inputs description	Variable Name	Value	Units
Wave Frequencies	wave_frequency	[0.5,1, 1.5, 2,2.5, 3, 3.5, 4,4.5, 5]	Rad/s
Wave Direction	wave_direction	[0]	Deg
Heading Angle Span	heading_angle_span	Deg	0
Generate Array Interaction Matrix	get_array_mat	true	bool
Degree of Freedom (DOF)	dofs	["Surge","Heave","Pitch"]	-
Shared DOF	shared_dof	[1,0,1,0,1,0]	-
Total Number of Generalized DOF	ndof	4	-
Angular Discretization of Inscribing Cylinder	cyl_theta	10	-
Vertical Discretization of Inscribing Cylinder	cyl_zeta	11	-
Mechanical Joints Definition for Multibody Systems	joints	Joint 1 see	-
Bodies Description	bodies	Body 0 see Table 3.16 Body 1 see Table 3.17	-
Water Depth	water_depth	100	m
PTO Damping	pto_damping	1.2e6	N/(m/s) or Nm/(rad/s)
Mooring Stiffness	mooring_stiffness	10000.0	N/m or Nm/rad
Additional Damping	additional_stiffness	0	N/(m/s) or Nm/(rad/s)
Additional Stiffness	additional_damping	0	N/m or Nm/rad
Capture Width Ratio (CWR)	capture_width_ratio	see Table 3.19	-
Hs (CWR)	hs_capture_width	see Table 3.19	M
Tp (CWR)	tp_capture_width	see Table 3.19	s
Wave Direction (CWR)	wave_angle_capture_width	0	deg
Wave Spectra: Directional Spreading	wave_spectral:angular_spreading_factor	0	-
Wave Spectra: Peak Enhancement Factor	wave_spectral:peak_enhancement_factor	3.3	-
Wave Spectra: Spectrum Shape	wave_spectral:spectrum_type	“JONSWAP”	-

TABLE 7.14: WAVE BODY 0 DEFINITION: SPAR

Inputs description	Variable Name	Value	Units
ID	ID	0	-
Moment of Inertia Tensor	MoI	[[94419615,0,0], [0,94497091,0], [0,0,28542225]]	kg m²
Body Mass	mass	878300	kg
Center of Gravity	cog	[0,0,-21.79]	m
Body Coordinate System Orientation in Euler Angles	axis_angles	[0,0,0]	Deg
Mesh Name	mesh	"Spar.dat"	-
Mesh Format	mesh_format	"Nemoh"	-
Mesh Vertexes and Panels	mesh_raw	[]	m

TABLE 7.15: WAVE BODY 1 DEFINITION: FLOATER

Inputs description	Variable Name	Value	Units
ID	ID	1	-
Moment of Inertia Tensor	MoI	[[20907301,0,0], [0,21306090,0], [0,0,37085481]]	kg m²
Body Mass	mass	727010	kg
Center of Gravity	cog	[0,0,-0.72]	m
Body Coordinate System Orientation in Euler Angles	axis_angles	[0,0,0]	Deg
Mesh Name	mesh	"Floater.dat"	-
Mesh Format	mesh_format	"Nemoh"	-
Mesh Vertexes and Panels	mesh_raw	[]	m

TABLE 7.16: WAVE JOINTS DEFINITION

Inputs description	Variable Name	Value	Units
ID	ID	0	-
Parent ID	parent	0	-
Child ID	child	1	-
Point of Application	point_of_application	[0,0,0]	m
Direction	joint_direction	[0,0,1]	m
Joint Type	type	"prismatic"	-

TABLE 7.17: MACHINE CWR AT COMPLEXITY 2

Hs \ Te	4.5	5.5	6.5	7.5	8.5	9.5	11	12	13	14	15	16	17	18
0.25	0	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0
0.75	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0
1.25	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0
1.75	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0
2.25	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0
2.75	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0
3.25	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0
3.75	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0	0	0	0
4.25	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0	0	0	0
4.75	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0
5.25	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0
5.75	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0
6.25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0
6.75	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0
7.25	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0
7.75	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0
8.25	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0

7.4 ENERGY CAPTURE (EC)

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

- For new Users, the tutorials give step-by-step instructions on using the tool,
- 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 Energy Capture module is used to evaluate the raw energy absorbed by an array of either Tidal or Wave energy devices. The module can be used in two modes: In the first mode, the User can estimate the array performance based on a given array layout, while in the second mode, the User let the system find the array layout that maximises the energy production of the array.

The Energy Capture module is one of the Deployment Design Tools. In the design flow, the Energy Capture is one of the first modules to run since it provides the devices' position used by the Energy Delivery, Energy Transformation, Station Keeping and Logistic and Marine

Operation modules. The Energy Capture module relies on the data provided by the Machine Characterization and the Site Characterization modules.

7.4.1 Overview of the EC Functionalities

The main purpose of the Energy Capture module is to estimate the annual energy production, the average power production and the hydrodynamic interaction within the array. The inputs are divided into three main categories:

- Farm – definition of the User, provided farm or definition of the optimization strategy to run
- Site – definition of the installation site, such as lease area boundary and energy flux
- Model – definition of the machine features, such as efficiency, number of generators, etc.…

The outputs of the module are divided into two categories:

- Farm – array layout, array efficiency, annual energy production and average power production
- Devices – the device's output comprise all the devices in the farm, and for each of them, the following metrics are given: device efficiency, device annual energy production and device average power production

The module can either be run in three levels of complexity low (complexity 1), medium (complexity 2) and high (complexity 3). The higher the complexity, the higher the inputs required by the system in term or site and machine.

7.4.2 Workflow for using the EC module

The workflow for using the Energy Capture module can is summarised in the graph below:

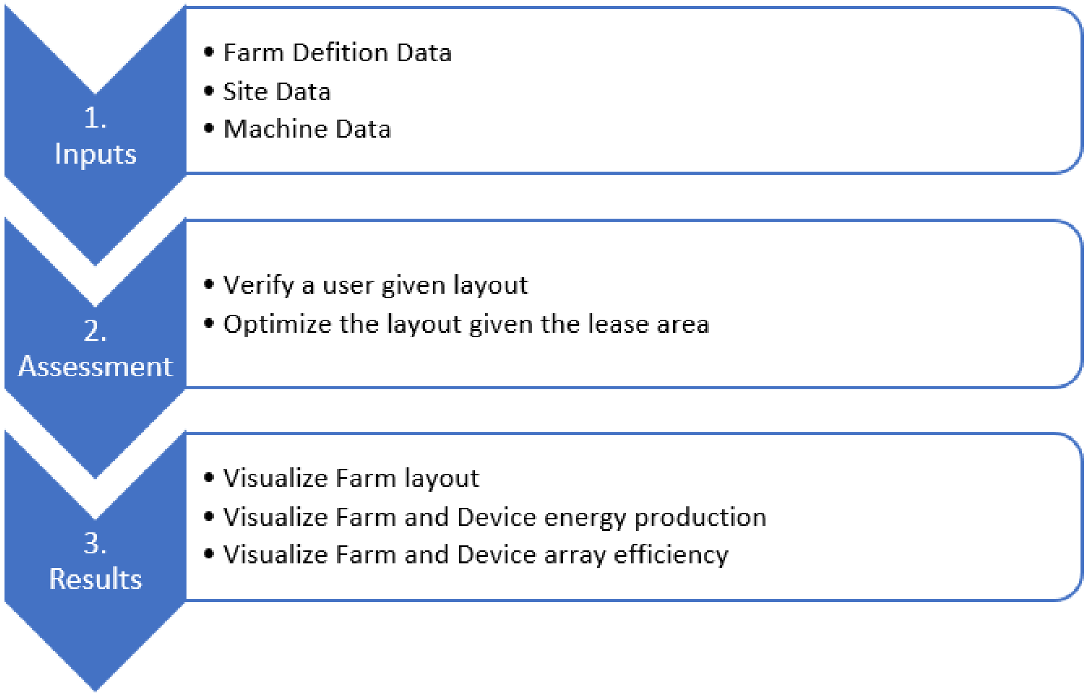


FIGURE 7.6: THE WORKFLOW FOR USING THE ENERGY CAPTURE MODULE

7.4.3 Overview of EC data requirements

This section summarises the types of input data required to complete the Energy Capture module. Full details and data specifications are given in the how-to guide on preparing data.

The modules receive the data from other modules and the User. In the standalone mode, the User will have to provide the data otherwise provided by other modules.

TABLE 7.18: SUMMARY OF REQUIRED INPUTS

Section	Description
Farm	▫ Number of Devices ▫ Array Layout ▫ Optimization strategy and constraints
Site	▫ Lease Area Boundary ▫ Energy Flux and Energy Distribution
Machine	▫ Efficiency (power coefficient or capture width ratio) ▫ Installation Constraints ▫ Machine functionality

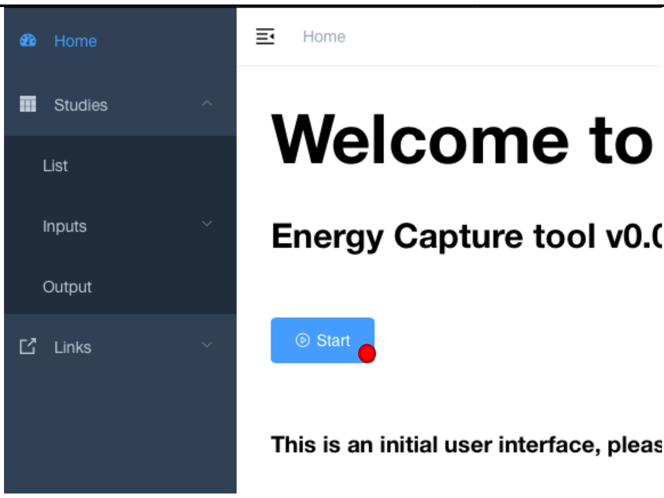
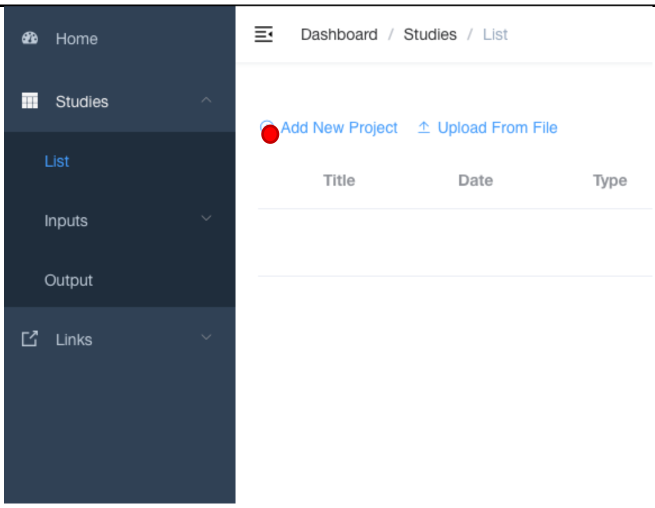
The machine functionality will range from a simple definition of the type down to the matrix for the Direct Matrix method's solution.

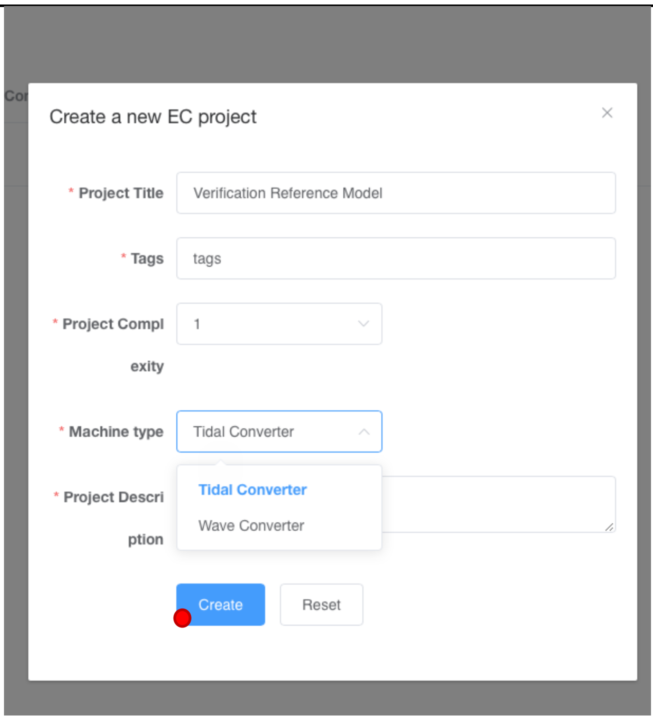
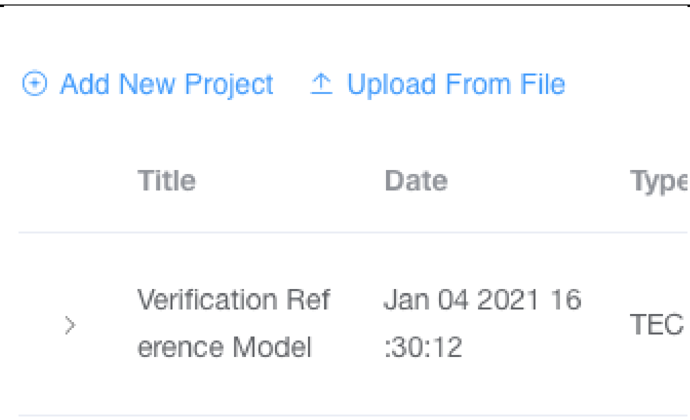
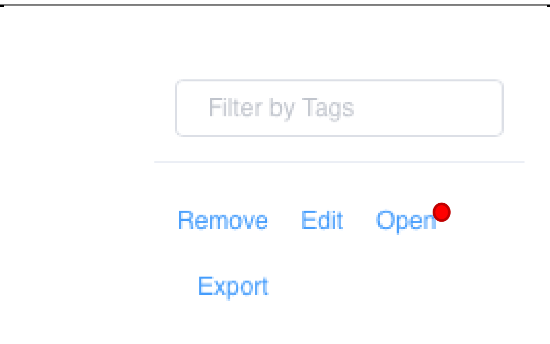
7.4.4 EC Tutorials

It is important to notice that the information contained in this section refers to the actual state of development of the module, which might vary if compared to the released version due to the feedback gathered by the Users in verification and validation tasks.

7.4.4.1 Creating a new Energy Capture study in standalone mode

Once logged into the server, the next step is to create a new study within the Energy Capture module.

	Click on the start button to visit the list of available projects.
	Click on the "Add New Project" to add a project.

	Fill the form based on the verification case to run. It is important to select the correct Machine Type and Project complexity. Click on the "Create" button to create the project.
	The project will appear in the Table in the middle of the screen.
	To open the project page, click on the "Open" button on the right-hand side of the table.

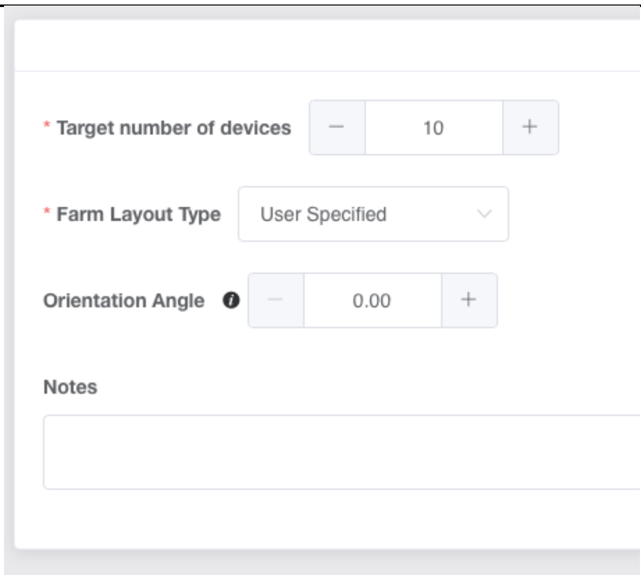
7.4.4.2 Using Energy Capture at low complexity in standalone mode

After a study has been created and opened, the user is guided to defining the three types of input previously described. For each of the input, the process is similar:

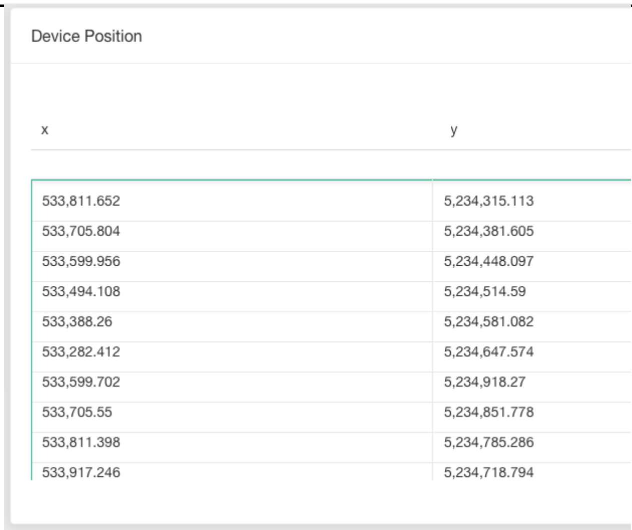
1) Fill the input in the given form or provide the necessary files
2) Save the inputs into the DB using the "Submit" button
3) Move to the next section

Please note that the data is not automatically saved, but it is the User responsibility to click the "Submit" button.

The three sections of the inputs can be filled in any order.

<table>
<tr><td>FARM INPUTS</td><td></td></tr>
<tr><td>
</td><td>Select the target number of devices: 10.

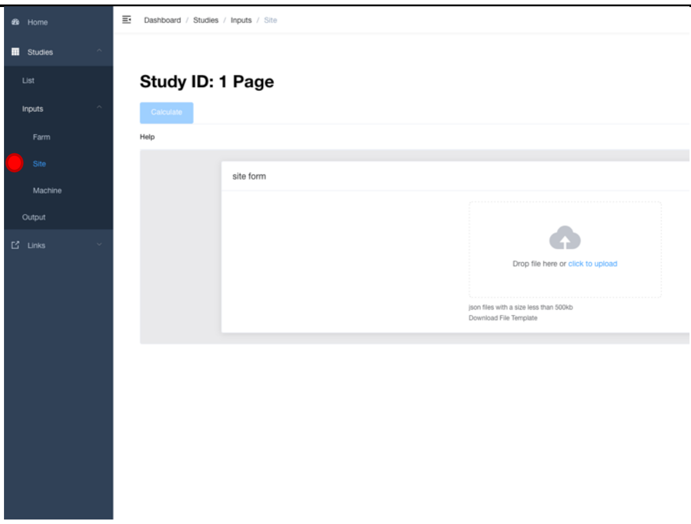
The layout is given by the User, so ensure that the "User Specified" option is selected.

Keep the orientation angle at 0.0deg.</td></tr>
<tr><td>
</td><td>Open the file RM1/RM3 layout in excel and copy (ctrl+c) the range A1:B10.

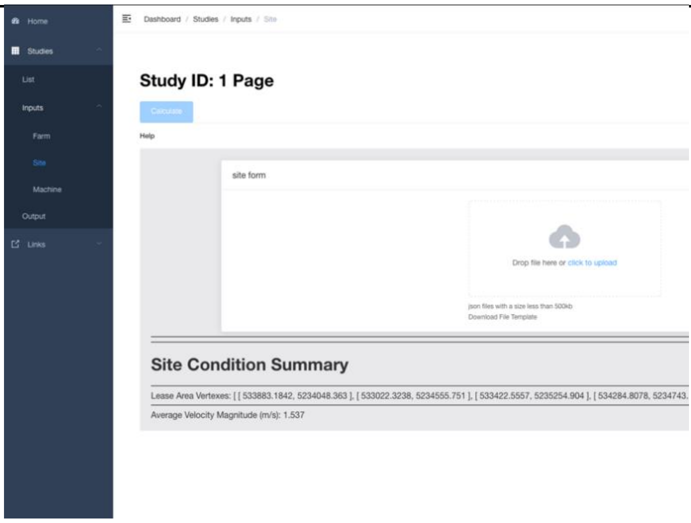
On the EC module, place the cursor on the first element of the x column and paste the clipboard content (crtl+v).

Click "Submit" to save the modification.

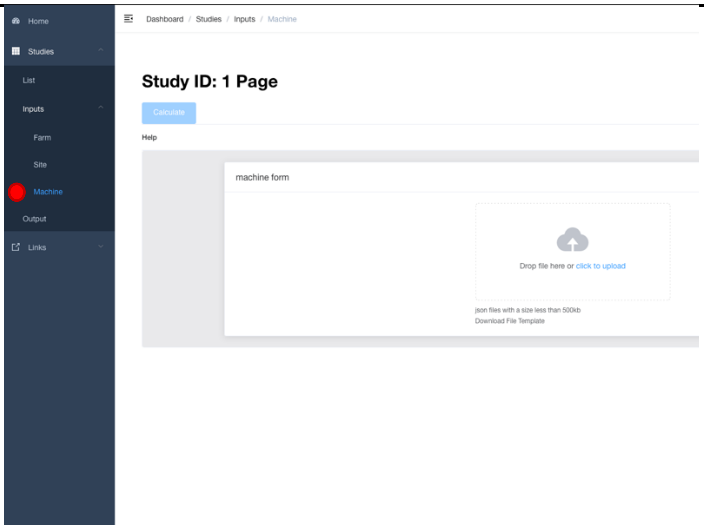
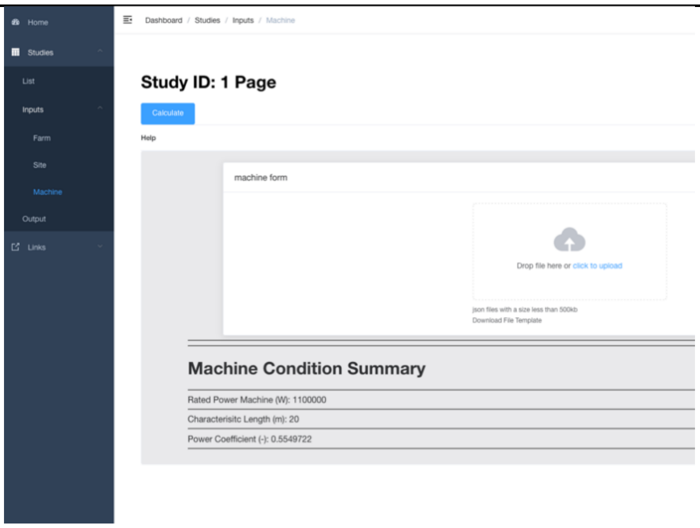
The data will be different for the RM1 and the RM3 cases.</td></tr>
</table>

<table>
<tr><th>SITE INPUTS</th><th></th></tr>
<tr><td>
</td><td>To navigate the site input page, click on the "input/site" on the side menu (left-hand side).

Drag and drop the *.json file corresponding to the verification case or use the click to upload to browse to the file.

If the file format is not correct, an error message will be displayed at the top of the page.</td></tr>
<tr><td>
</td><td>If successful, a summary of the site condition will be displayed at the bottom of the page.

NOTE: due to an error in creating the summary item, some of the items might not render correctly. Try to click on the farm view and go back to the site view, this should solve the visualisation problem.</td></tr>
</table>

MACHINE INPUTS	
	To navigate the machine input page, click on the "input/machine" on the side menu (left-hand side). Drag and drop the *.json file corresponding to the verification case or use the click to upload to browse to the file. If the file format is not correct, an error message will be displayed at the top of the page.
	If successful, a summary of the machine definition will be displayed at the bottom of the page. NOTE: due to an error in creating the summary item, some of the items might not render correctly. Try to click on the farm view and go back to the machine view; this should solve the visualization problem.

Once the process of input the data is terminated, the "Calculate" button will be enabled (right top side of the page). The Calculate button will launch the background calculation.

The User is then redirected to the output page. The outputs will be automatically fetched once the calculation is finished.

7.4.5 EC How-to Guides

7.4.5.1 How to prepare data for using the Energy Capture module

The User can enter the array layout definition either by editing the layout table one element at a time, or by uploading an excel file. The file must have the data stored in column format. The file must have the following headers respectively in the first row at column A and B: easting, northing. The respective data can be filled from row 2 downwards.

The preparation of the site and machine data is done directly in json format. The json format can be edited in any text editor.

The process to self-generate the json file is feasible for the low and medium complexity case and for the complexity high in the case of a tidal turbine.

For the wave case at high complexity, the process to generate the data is unfeasible since there is no commercial software available to estimate the interaction matrices to be used in the module.

7.5 ENERGY TRANSFORMATION (ET)

This is the User Manual for the Beta version of the Energy Transformation ET module within the DTOceanPlus suite of tools. The Alpha version was released in May 2020, and it is described in D5.4.

The ET module computes the transformation of energy from the power captured to the electrical output of each device in an array of Ocean Energy Systems (OES). It is one of the Deployment Design Tools, run after Energy Capture and Machine characterization and before Energy Delivery, as shown in Figure 1.1.

7.5.1 Overview of the ET Functionalities

The main purpose of the Energy Transformation module is to design the different energy transformation steps:

- Hydrodynamic to Mechanic (Mechanical Transformation);
- Mechanic to Electric (Electrical Transformation) and Control;
- Electric to Grid (Grid Conditioning).

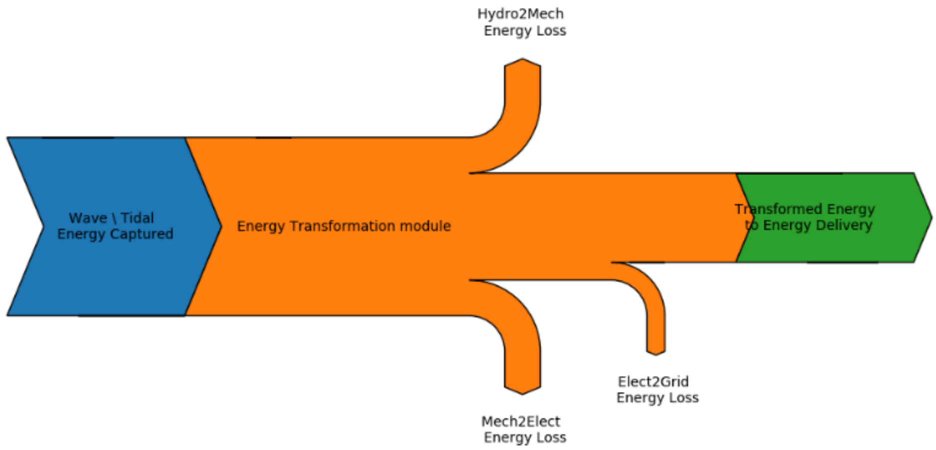


FIGURE 7.7: ENERGY FLOW REPRESENTATION IN THE ENERGY TRANSFORMATION MODULE

The main outputs are costs, efficiency, reliability and bill of materials of the three energy transformation steps. The module can either be run in simplified mode at each transformation step, which corresponds to complexity 1, or in advanced mode, in case of complexity 2 and 3.

From a User perspective, there is no substantial difference in the ET module computation between complexity 2 and 3: the variation is that at complexity 2, the data is considered from a series of existing items in the DTOceanPlus Catalogue, while at complexity 3, the User can introduce their own inputs in the ET module, updating so the DTOceanPlus Catalogue. This allows the user to run the tool considering different complexities at each transformation steps.

Depending on the complexity levels selected, a global complexity level (called ET Cpx) will be assigned considering the following practices:

- ET Cpx 1: At least one of three transformation steps has complexity 1
- ET Cpx 2: all the three transformation steps have complexity 2
- ET Cpx 3: At least one of three transformation steps has complexity 3
- Complexity 1 at one transformation step is not compatible with complexity 3 at any another transformation step. Therefore, if the User selects complexity 1 at least for one transformation step of the three, it will not be possible to run the module at ET Cpx 2 or 3.

7.5.2 Workflow for using the ET module

The workflow for using the Energy Transformation module can be summarised as 1) provide inputs, 2) perform a design, and 3) view the results, as shown in Figure 7.8.

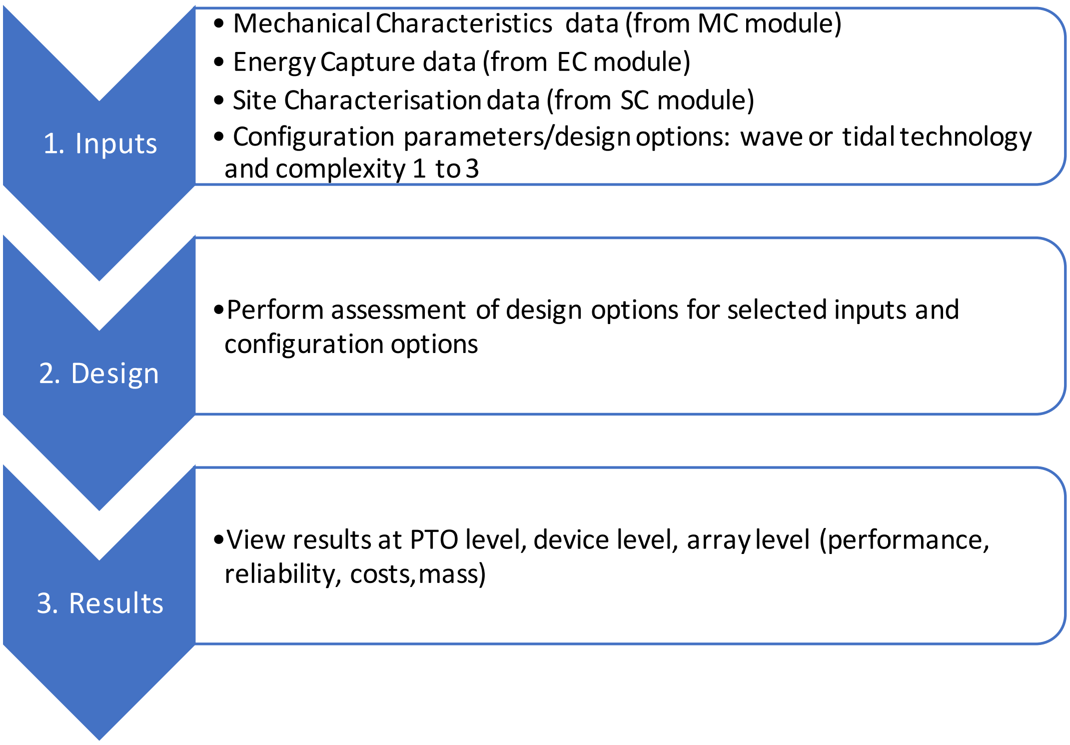


FIGURE 7.8: THE WORKFLOW FOR USING THE ENERGY TRANSFORMATION MODULE

7.5.3 Overview of ET data requirements

This section summarises the types of input data required to run the Energy Transformation module. Full details and data specifications are given in section 3.4.4. The required inputs to run the module are summarised in the following tables.

ET module will obtain inputs from 3 different sources:

- External modules
- User inputs from the GUI
- Component Database (Catalogue)

7.5.3.1 Inputs from external modules

Depending on the complexity level and the technology, different inputs will be needed:

- The resource from the Site Characterisation module
- The absorbed energy and the device motion from the Energy Capture tool
- The device characteristics from the Machine Characterisation module

In standalone mode, these inputs will be uploaded to the ET study through 3 independent json files. All external modules input studies must have the same complexity level. For more information about the format of the inputs, check the how-to guide section.

Site characterization SC

As mentioned in D5.2, the outcome of SC is fully independent of the complexity on which SC is run. Therefore, its output parameters are the same for every complexity of SC. However, in complexity 3, the values can be given for different sea states so that the arrays can have more than one position (one per sea state). At complexity 3, there will be an array of parameters to define each sea state.

Wave energy converter (called "waves" in SC)

The following table shows the inputs parameters from SC, in the case of Wave energy technology, independently from the complexity level of SC module.

TABLE 7.19: INPUTS FROM SITE CHARACTERISATION WAVE ENERGY CONVERTER

Variables	Description	Object Format example
"id"	Id of the SC study	"id": [0, 1, 2]
"HS"	Significant wave height	"HS": [0.5, 1, 2]
"TP"	Wave period	"TP": [7, 6, 7]
"p"	Probability of occurrence	"p": [0.5, 0.5, 0.5]

Tidal energy converter (called "currents" in SC)

The following table shows the inputs parameters from SC, in the case of tidal energy technology, independently from the complexity level of the SC module.

TABLE 7.20: INPUTS FROM SITE CHARACTERISATION TIDAL ENERGY CONVERTER

Variables	Description	Object Format example
“complexity”		"complexity": 2
“id”	Id of the SC study	"id": [0, 1, 2]
“p”	Probability of occurrence	"p": [0.5, 0.5, 0.5]

Machine Characterisation MC

MC module corresponds to the second input module to ET. The data requirements from MC are presented below:

Wave Energy Converter

In the case of wave energy technology design, the input variables to the ET module are exactly the same at each MC complexity level with a slight difference in the format of the digital object “pto_damping” as shown below.

TABLE 7.21: INPUTS FROM MACHINE CHARACTERISATION WAVE ENERGY CONVERTER

Variables	Description	Object Format example
“id”	Id of the MC study	"id": [1]
“technology”	Type of ocean energy technology (either wave or tidal)	"technology": WEC
“complexity”	Complexity of MC	"complexity": 1
“pto_damping”	Damping of the PTO to absorb energy from the resource	MC complexity level 1 and 2: "pto_damping": [1000000]
		MC complexity level 3: "pto_damping": [[548000, 0, 0, 0, 0, 0], [0, 548000, 0, 0, 0, 0], [0, 0, 548000, 0, 0, 0], [0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0]]

Tidal Energy Converter

In the case of tidal energy technology, the input paraments from MC module to ET module vary according to the complexity level of MC module, as shown in the following tables.

<u>MC Complexity level 1</u>

TABLE 7.22: INPUTS FROM MACHINE CHARACTERISATION TIDAL ENERGY CONVERTER (CPX1)

Variables	Description	Object Format example
“id”	Id of the MC study	"id": 1
“technology”	Type of ocean energy technology (either wave or tidal)	"technology": "TEC"
“complexity”	Complexity of MC	"complexity": 1
“cp”	Power coefficient	"cp": 0.37
“number_rotor”	Number of rotors per device	"number_rotor": 2

MC Complexity level 2

TABLE 7.23: INPUTS FROM MACHINE CHARACTERISATION TIDAL ENERGY CONVERTER (CPX2)

Variables	Description	Object Format example
"id"	Id of the MC study	"id": 1
"technology"	Type of ocean energy technology (either wave or tidal)	"technology": "TEC"
"complexity"	Complexity of MC	"complexity": 2
"cp"	Power coefficient	"cp": 0.37
"number_rotor"	Number of rotors per device	"number_rotor": 2
"tip_speed_ratio"	Tip Speed Ratio value	"tip_speed_ratio": 5.79
"ct"	Thrust Coefficient	"ct": 0.43
"cut_in_velocity"	Cut in velocity value	"cut_in_velocity": 0.5
"cut_out_velocity"	Cut out velocity value	"cut_out_velocity": 3

MC Complexity level 3

TABLE 7.24: INPUTS FROM MACHINE CHARACTERISATION TIDAL ENERGY CONVERTER (CPX3)

Variables	Description	Object Format example
"id"	Id of the MC study	"id": 1
"technology"	Type of ocean energy technology (either wave or tidal)	"technology": "TEC"
"complexity"	Complexity of MC	"complexity": 3
"cp"	Power coefficient	"cp": [1.0, 1.0, 1.0]
"number_rotor"	Number of rotors per device	"number_rotor": 2
"tip_speed_ratio"	Tip Speed Ratio value	"tip_speed_ratio": 5.79
"ct"	Thrust Coefficient	"ct": [1.0, 1.0, 1.0]
"cut_in_velocity"	Cut in velocity value	"cut_in_velocity": 0.5
"cut_out_velocity"	Cut out velocity value	"cut_out_velocity": 3
"cp_ct_velocity"	Velocities at which cp and ct coefficients are given	"cut_out_velocity": [1.0, 1.0, 1.0]

Energy Capture EC

The third input module to ET is the EC module, which inputs parameters to ET are shown below.

Wave energy converter

In the case of wave energy technology, the input variables to the ET module are exactly the same at each complexity level, but the format will change; for more information, go to the how-to guide section.

TABLE 7.25: INPUTS FROM ENERGY CAPTURE WAVE ENERGY CONVERTER

Variables	Description	Object Format example
"id"	Id of the EC study	"id": 1
"technology"	Type of ocean energy technology (either wave or tidal)	"technology": "WEC"
"complexity"	Complexity of MC	"complexity": 3
"number_devices"	Number of devices	"number_devices": 10

"CapturedPower"	Capture power per condition	"captured_power_per_condition": { "capturedPower": [10001] "siteConditionID": 2}
"siteConditionID"	Id of Site condition	

Tidal energy converter

In the case of tidal energy technology, the input paraments from the EC module to the ET module vary according to the complexity level of the EC module, as shown in the following tables.

<u>EC Complexity level 1</u>

TABLE 7.26: INPUTS FROM ENERGY CAPTURE TIDAL ENERGY CONVERTER (CPX1)

Variables	Description	Object Format example
"id"	Id of the EC study	"id": 1
"technology"	Type of ocean energy technology (either wave or tidal)	"technology": "TEC"
"complexity"	Complexity of MC	"complexity": 3
"number_devices"	Number of devices	"number_devices": 10
"CapturedPower"	Capture power per condition	"captured_power_per_condition": { "capturedPower": [10001] "siteConditionID": 2}
"siteConditionID"	Id of site condition	
"deviceID"	ID of a specific device in the tidal farm	"array_velocity_field": [{"deviceID": 1, "hub_velocity": 2.3}]
"hub_velocity"	Current speed at turbine hub	
"main_dim_device"	Equivalent to the diameter of turbine device	"main_dim_device": 20

<u>EC Complexity level 2</u>

TABLE 7.27: INPUTS FROM ENERGY CAPTURE TIDAL ENERGY CONVERTER (CPX2)

Variables	Description	Object Format example
"id"	Id of the EC study	"id": 1
"technology"	Type of ocean energy technology (either wave or tidal)	"technology": "TEC"
"complexity"	Complexity of MC	"complexity": 3
"number_devices"	Number of devices	"number_devices": 10
"CapturedPower"	Capture power per condition	"captured_power_per_condition": { "capturedPower": [10001], "siteConditionID": 2}
"siteConditionID"	ID of a specific site in the tidal farm	
"deviceID"	ID of a specific device in the tidal farm	"array_velocity_field": [{"deviceID": 1, "hub_velocity": 2.3}]
"hub_velocity"	Current speed at turbine hub	
"rotor_diameter"	Size of tidal turbine diameter	" rotor_diameter ": 20

EC Complexity level 3

TABLE 7.28: INPUTS FROM ENERGY CAPTURE TIDAL ENERGY CONVERTER (CPX3)

Variables	Description	Object Format example
"id"	Id of the EC study	"id": 1
"technology"	Type of ocean energy technology (either wave or tidal)	"technology": "TEC"
"complexity"	Complexity of MC	"complexity": 3
"number_devices"	Number of devices	"number_devices": 10
"CapturedPower"	Capture power per condition	"captured_power_per_condition": { "capturedPower": [10001] "siteConditionID": 2}
"siteConditionID"	id of site condtion	
"deviceID"	ID of a specific device in the tidal farm	"array_velocity_field": [{"deviceID": 1, "hub_velocity": 2.3}]
"hub_velocity"	Current speed at turbine hub	
"rotor_diameter"	Size of tidal turbine diameter	" rotor_diameter": 20

7.5.3.2 User inputs from the GUI

The User will set basic information about the ET study and provide the main inputs of each transformation stage depending on the complexity level and technology.

- **Study**: Name, description and standalone mode (yes/no)
- **General inputs**: Parallel PTOs and shutdown flag
- **Mechanical inputs**: Main mechanical transformation parameters as power, type of conversion, transformation ratio, etc.
- **Electrical inputs**: Main generator parameters like rated power, voltage, frequency, etc.
- **Grid inputs**: Main power electronics parameters like rated power, DC-link voltage, switching frequency, etc.

Wave energy converter

TABLE 7.29: USER INPUT GUI, WAVE ENERGY CONVERTER, CPX1, CPX2, CPX3, DEVICE LEVEL (MECHANICAL CONVERSION, ELECTRICAL CONVERSION, GRID CONDITIONING)

Parameter	Unit Measure
DEVICE level	
Mechanical conversion complexity	1/2/3 [-]
Electrical conversion complexity	1/2/3 [-]
Grid integration complexity	1/2/3 [-]
Mechanical conversion type	Air Turbine / Hydraulic / Gearbox
Electrical conversion type	SCIG
Grid conditioning type	B2B
Number of PTO per device	[-]
Shutdown flag	[-]

TABLE 7.30: USER INPUT GUI, WAVE ENERGY CONVERTER, CPX1, CPX2, CPX3, PTO LEVEL (MECHANICAL CONVERSION, ELECTRICAL CONVERSION, GRID CONDITIONING)

<table>
<tr><th colspan="2">Parameter</th><th>Unit Measure</th></tr>
<tr><th colspan="3">PTO level Complexity 1</th></tr>
<tr><td colspan="2">Mechanical Conversion Size (Max Power)</td><td>kW</td></tr>
<tr><td colspan="2">Mechanical Transmission Ratio</td><td>-</td></tr>
<tr><td colspan="2">Electrical Conversion Rated Power</td><td>kW</td></tr>
<tr><td colspan="2">Grid Conditioning Rated Power</td><td>kW</td></tr>
<tr><th colspan="3">PTO level Complexity 2/3</th></tr>
<tr><th colspan="3">Mechanical conversion</th></tr>
<tr><td rowspan="4">Air Turbine</td><td>Turbine Type</td><td>Wells / Impulse</td></tr>
<tr><td>Turbine diameter</td><td>m</td></tr>
<tr><td>Turbine surface water level area</td><td>m²</td></tr>
<tr><td>Turbine transmission ratio</td><td>[-]</td></tr>
<tr><td rowspan="3">Hydraulic</td><td>Hydraulic motor size</td><td>m³/rad</td></tr>
<tr><td>Cross-section piston area</td><td>m²</td></tr>
<tr><td>Transmission ratio</td><td>[-]</td></tr>
<tr><td rowspan="2">Linear to rotational</td><td>Rated power</td><td>kW</td></tr>
<tr><td>Transmission ratio</td><td>[-]</td></tr>
<tr><th colspan="3">Electrical conversion type</th></tr>
<tr><td colspan="2">Rated power</td><td>kW</td></tr>
<tr><td colspan="2">Rated rms voltage</td><td>V</td></tr>
<tr><td colspan="2">Nominal frequency</td><td>Hz</td></tr>
<tr><td colspan="2">Generator inductance</td><td>Hr</td></tr>
<tr><td colspan="2">Generator resistance</td><td>Ohm</td></tr>
<tr><td colspan="2">Generator pole pairs</td><td>[-]</td></tr>
<tr><td colspan="2">Maximum to nominal torque</td><td>[-]</td></tr>
<tr><td colspan="2">Maximum to nominal voltage</td><td>[-]</td></tr>
<tr><td colspan="2">Generator pole pairs</td><td>[-]</td></tr>
<tr><td colspan="2">Electrical conversion class</td><td>[-]</td></tr>
<tr><th colspan="3">Grid Conditioning type</th></tr>
<tr><td colspan="2">Rated power (grid)</td><td>W</td></tr>
<tr><td colspan="2">DC Link voltage</td><td>V</td></tr>
<tr><td colspan="2">Switching frequency</td><td>Hz</td></tr>
<tr><td colspan="2">Grid rms voltage</td><td>V</td></tr>
<tr><td colspan="2">Resistance</td><td>Ohm</td></tr>
<tr><td colspan="2">Inductance</td><td>Hr</td></tr>
<tr><td colspan="2">Required cosfi</td><td>[0-1]</td></tr>
<tr><td colspan="2">Grid frequency</td><td>Hz</td></tr>
</table>

Tidal energy converter

TABLE 7.31: USER INPUT GUI, TIDAL ENERGY CONVERTER, CPX1, CPX2, CPX3, DEVICE LEVEL AND PTO LEVEL (MECHANICAL CONVERSION, ELECTRICAL CONVERSION, GRID CONDITIONING)

Parameter	Unit Measure
PTO level Complexity 1	
Mechanical Conversion Size (Max Power)	kW
Mechanical Transmission Ratio	-
Electrical Conversion Rated Power	kW
Grid Conditioning Rated Power	kW
PTO level Complexity 2/3	
Mechanical conversion (Gearbox)	
Gearbox_P_rated	kW
Gearbox_transmission_ratio	[-]
Electrical conversion type	
Rated power	kW
Rated rms voltage	V
Nominal frequency	Hz
Generator inductance	Hr
Generator resistance	Ohm
Generator pole pairs	[-]
Maximum to nominal torque	[-]
Maximum to nominal voltage	[-]
Generator pole pairs	[-]
Electrical conversion class	[-]
Grid Conditioning type	
Rated power (grid)	W
DC Link voltage	V
Switching frequency	Hz
Grid rms voltage	V
Resistance	Ohm
Inductance	Hr
Required cosfi	[0-1]
Grid frequency	Hz

7.5.3.3 Catalogue inputs

Apart from external inputs and User inputs, there are many other data needed for the detailed computation of the ET results. Especially specific parameters of each component in the transformation stages.

As this data is not usually known by mid-level Users, default data is included in a catalogue.

Catalogue parameters are used by all transformation stages in complexities 2 and 3 as the models used are the same. These parameters will be modifiable only in complexity 3.

From a User perspective, there is no substantial difference in the ET module computation between complexity 2 and 3: the variation is that at complexity 2, the catalogue input data is fixed in the DTOceanPlus Catalogue, while at complexity 3, the User can introduce his own catalogue inputs data in the ET module, updating so the DTOceanPlus Catalogue. This allows the User to run the tool considering different complexities at each transformation steps.

Air turbine

TABLE 7.32: USER INPUT FROM CATALOGUE, MECHANICAL TRANSFORMATION, AIR TURBINE

Type	Units
Manufacturer	
date	aaaa/mm/dd
Mass	[kg/m^3]
Cost	[€]
phi_mech	[-]
pi_mech	[-]
phi_hyd	[-]
psi_hyd	[-]
phi_eff	[-]
eta_eff	[-]
shaftD	m
fatigue_life[[m1,log(a)],[m2,log(a2)]]	[-]
a_c	[-]

Gearbox

TABLE 7.33: USER INPUT FROM CATALOGUE, MECHANICAL TRANSFORMATION, GEARBOX

id	Type
Type	
Manufacturer	
date	aaaa/mm/dd
maxP_rel	
power_loads_norm	[-]
eff_levels	[-]
fatigue_life[[m_step,log_a],[]]	
Cost	€/W
Mass	kg/W
shaftD	m/W

Hydraulic

TABLE 7.34: USER INPUT FROM CATALOGUE, MECHANICAL TRANSFORMATION, HYDRAULIC

id	Type
Type	
Manufacturer	
date	aaaa/mm/dd
hyd_mot_eff	
Bulk_Mod	[Pa]
Oil [oil_visc, oil_dens]	[Pa·s] , [kg/m3]

Loss coefs [Laminar leakage coeff, Turbulent leakage coeff, Viscous loss coeff , Friction loss coeff,Hydr Loss coeff (motor)]	[-],[-],[-],[-],[-]
Shaft Diam	[m]
Mass	[kg/W]
fatigue_life[[m1,log(a)],[m2,log(a2)]]	
cost	[€/W]
maxflow_rel	

Generator

TABLE 7.35: USER INPUT FROM CATALOGUE, MECHANICAL TRANSFORMATION, GENERATOR

id	Type
Type	
Manufacturer	
date	
I_nom	Pnom/A
Gen_mass	Kg/W
cost	€/W
life[Class_A[k,ko,Temp_max[ºC]],Class_B[k,ko,Temp_max[ºC]], Class_F[k,ko,Temp_max[ºC]],Class_H[k,ko,Temp_max[ºC]]]	
wind_mass_fraction	[-]
Res	W/ohm
Shaft Diameter	W/m
sigma_e	
sigma_h	
Magnetic Flux Density	[T]
phi_cos	[-]
om_shaft_norm	[-]
eff_levels	[-]
thick_max	mm

Power converter

TABLE 7.36: USER INPUT FROM CATALOGUE, GRID TRANSFORMATION, GRID CONDITIONING

Parameter	Units
id	
Type	
Manufacturer	
date	
Cost	€/W
life	[-]
temp	ºC
mass	kG/W
IGBT150	Vceo[V], Rce[ohm], a[-], b[-], c[-], Vnom[V]]
Diode150	Vfo[V],Rt[ohm],a[-],b[-],c[-],Vnom[V
IGBT450	Vceo[V], Rce[ohm], a[-], b[-], c[-], Vnom[V]
Diode450	Vfo[V],Rt[ohm],a[-],b[-],c[-],Vnom[V]]
IGBT800	Vceo[V], Rce[ohm], a[-], b[-], c[-], Vnom[V]]
Diode800	Vfo[V],Rt[ohm],a[-],b[-],c[-],Vnom[V]]
IGBT1600	[Vceo[V], Rce[ohm], a[-], b[-], c[-], Vnom[V]]

Diode1600	Vfo[V],Rt[ohm],a[-],b[-],c[-],Vnom[V]]

Control

TABLE 7.37: USER INPUT FROM CATALOGUE, CONTROL

id	Units
Type	Passive/User defined
adim_vel	[-]
Power_levels	
Load_levels	
Load_ranges	

7.5.4 ET Tutorials

The use of the Energy Transformation tool will be done in 3 steps:

1. Create an Energy Transformation Study
2. Insert User inputs
3. Analyse the outputs

7.5.4.1 Create an ET Study in Standalone Mode

Once logged into the server, the next step is to create a new study within the Energy Transformation 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 'ET Studies' and click 'Create Energy Transformation study'.

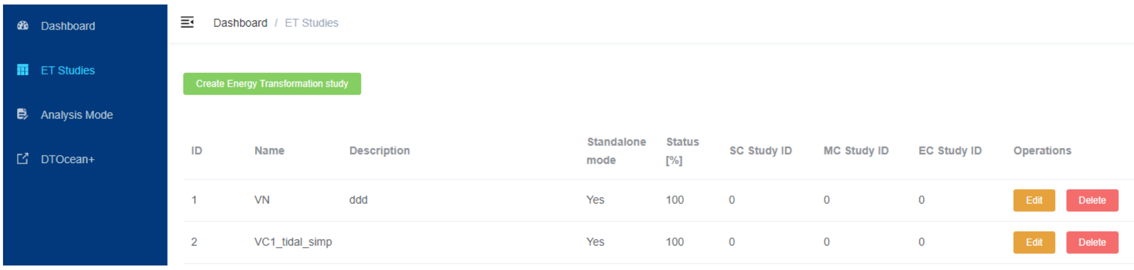


FIGURE 7.9: EXAMPLE OF CREATING AN ENERGY TRANSFORMATION STUDY

2. Fill in an appropriate name and description to identify your study.

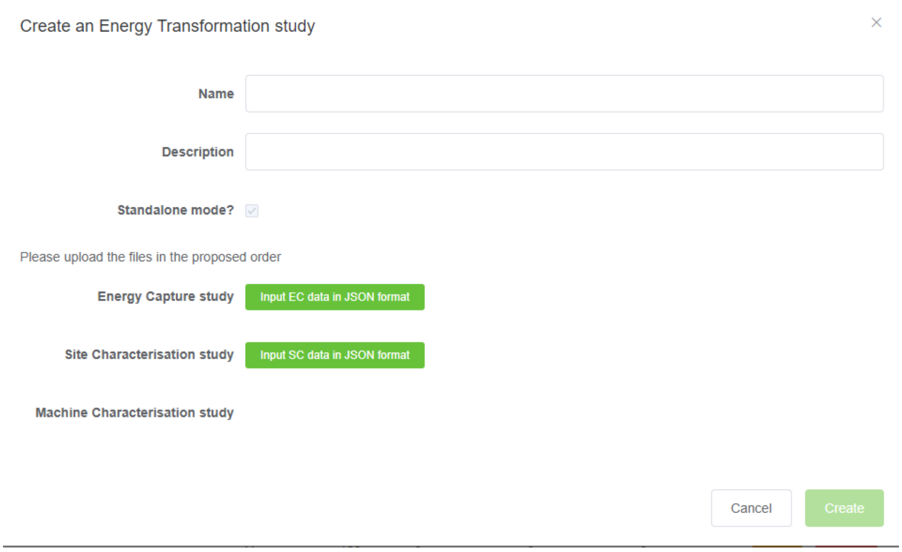


FIGURE 7.10: EXAMPLE OF CREATING A NEW STUDY II

3. Select if the study will run in Standalone or not. In the current version, only Standalone mode is available
4. In Standalone Mode, before creating the ET study, the external modules files must be uploaded. Be sure to upload the json files in the proposed order (EC, SC and MC). MC upload will only be enabled after uploading the EC file. All external modules files must have the same complexity level. Otherwise, an error message will be shown.

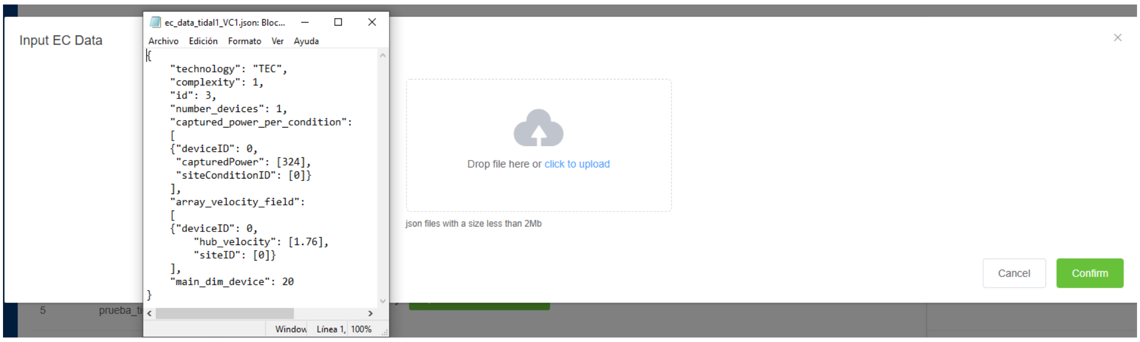


FIGURE 7.11: EXAMPLE OF HOW TO INCLUDE A .JSON ASN AN INPUT AT STANDALONE MODE

5. Once the necessary data has been completed, the 'Create' button will be enabled. Click 'Create' to save these inputs and return to the list of studies.
6. From the list of studies, click 'Edit' to update the description of the study or upload a new external module input file or 'Delete' to permanently remove a study.
7. In case of updating the external modules, again, upload the files in the proposed order (EC, SC and MC). If not all the files are to be uploaded, ensure that if the EC file is updated, MC is uploaded again even if the file is the same. This is because the tool updates the internal variables during the MC upload.

After the creation of the study with external modules inputs, the status variable will be 40%.

[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 Analysis Mode: Insert User inputs

After creating a study, the User can continue creating other studies or proceed to insert the inputs to an existing study.

1. In the left menu, select 'Analysis Mode'. The list of the available studies will be shown.
2. Select the study to insert the inputs. A new window, 'Analysis Mode Inputs' will be shown with the main study details: Name, description, technology and standalone mode.

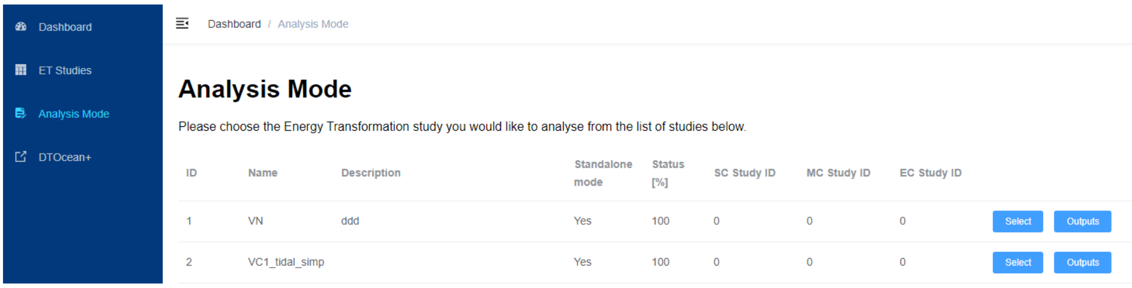


FIGURE 7.12: EXAMPLE OF SELECTING AN STUDY AT ANALISIS MODE

3. Five categories of input data appear. The different inputs will be displayed when clicking the name of the category.

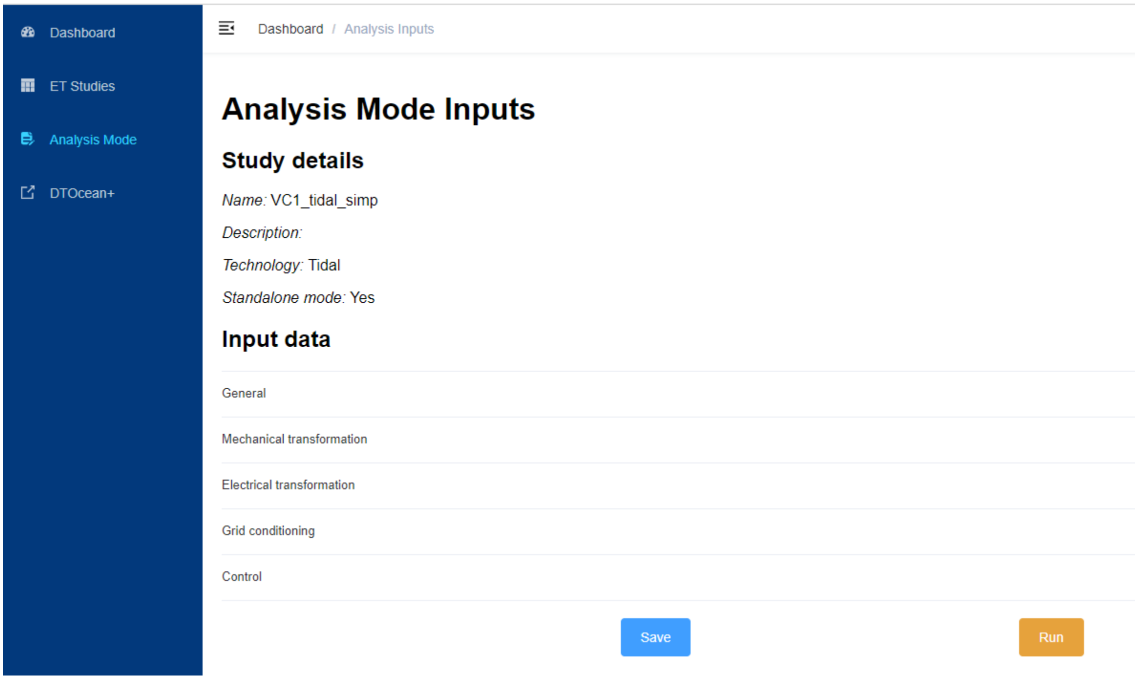


FIGURE 7.13: FIVE CATEGORIES GUI INPUT DATA

4. Click the name of each category sequentially and insert the necessary inputs in the drop-down menus. Note that the tool will always show a default variable that the user can modify. In mechanical, electrical and grid conditioning categories, select the complexity level. The tool will then display the needed User inputs for the selected complexity level, taking into account the technology.
5. Once all the inputs have been introduced, the buttons 'Save' and 'Run' are enabled.
    a. Click 'Save' to save the introduced inputs in the database of the study
    b. Click 'Run' to save the introduced inputs in the database of the study and run the study. The tool will automatically open the 'Outputs' window

The Status variable will be 70% when the User inputs are saved and 100% when the study is run and the outputs generated.

7.5.4.3 Analyse the outputs

Once the study has been run, the results will be available at the 'Outputs' window.

The outputs are categorized by array, device and PTO. Outputs can be seen in the graphical interface or downloaded.

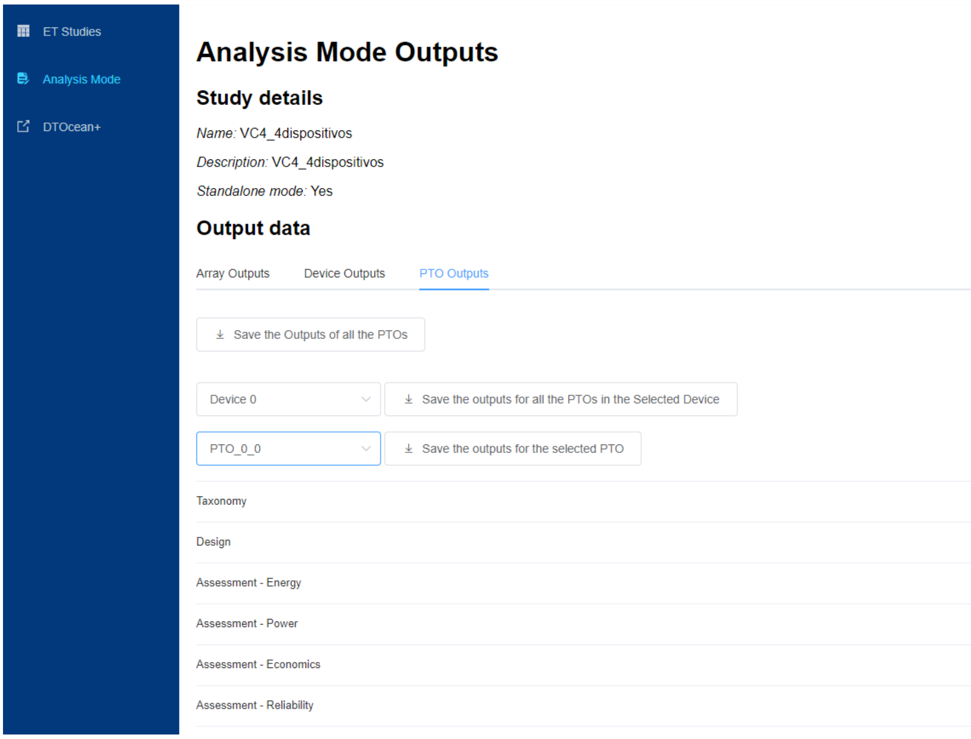


FIGURE 7.14: EXAMPLE OF ENERGY TRANSFORMATION OUTPUTS

Note that the tool is very sensitive; a bad design will lead to a misperformance of the system. If the results are not satisfactory, check if the external module's inputs are the desired and try with other input values.

7.5.5 ET How-to Guides

7.5.5.1 How to prepare external modules data for using the Energy Transformation module. Standalone case.

This guide summarises the data requirements and specifications for running the Energy Transformation module in full complexity standalone mode. The tool requires inputs from Site Characterisation, Machine Characterisation and Energy Capture. The needed data will be different depending on the complexity level and the device technology (Wave or Tidal).

For all external modules, the input data must be uploaded in a json file.

SITE CHARACTERISATION INPUT DATA

The following parameters are needed from SC and must be included in the json file.

- "technology" : "WEC" for Wave or "TEC" for Tidal
- "complexity": 1, 2, or 3
- "Hs": significant wave height. Only for wave technology
- "Tp": wave period
- "Occ": occurrence
- "id": site id

Examples are shown below. For complexities 1 and 2 only one sea state is considered:

```
{
    "technology": "WEC",
    "complexity": 1,
    "Hs": [2],
    "Tp": [7],
    "Occ": [1],
    "id": [1]
}
```

In the case of complexity 3, more than one sea state can be considered.

```
{
    "technology" : "WEC",
    "complexity": 3,
    "Hs": [2, 2, 3, 3, 2, 2],
    "Tp": [6, 6, 7, 7, 8, 8],
    "Occ": [0.16, 0.16, 0.16, 0.16, 0.16, 0.16],
    "id": [1, 2, 3, 4, 5, 6]
}
```

Note that for tidal technology, the "Hs" parameter is not needed.

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ENERGY CAPTURE INPUT DATA

Again, different inputs are needed depending on technology and complexity level.

The following parameters are needed from EC and must be included in the json file.

Wave technology:

- "technology":"WEC",
- "complexity":1, 2 or 3
- "number_devices": Number of devices in the array.
- "captured_power_per_condition": It will be an array of as many elements as the number of devices. Each element will consist of:
  - "deviceID": device Id.
  - "capturedPower": captured power of the device measured in kW
  - "siteConditionID": site condition id of the device

For Tidal technology, information about the device motion and rotor size is also needed:

- "array_velocity_field": It will be an array of as many elements as the number of devices. Each element will consist of:
  - "deviceID": device Id.
  - "hub_velocity": linear velocity of the resource at the hub of the rotor in m/s
  - "siteID": site condition id of the device
- "main_dim_device" in complexity 1 or "rotor_diameter" in complexities 2 and 3: gives information about the dimension of the tidal device in m

Examples are shown below. For complexities 1 and 2 only one sea state is considered:

```
{
    "technology": "WEC",
    "complexity": 1,
    "id": 3,
    "number_devices": 2,
    "captured_power_per_condition":[
    {"deviceID": 0,
     "capturedPower": [100],
     "siteConditionID": [0]},
    {"deviceID": 1,
     "capturedPower": [150],
     "siteConditionID": [0]}]
}
```

In case of complexity 3, more than one sea state can be considered.

```
{
    "technology": "TEC",
    "complexity": 3,
    "id": 1,
    "number_devices": 2,
    "captured_power_per_condition":
    [
    {"deviceID": 0,
     "capturedPower": [10011, 10012, 10013, 10014, 10015, 10016],
     "siteConditionID": [0, 1, 2, 3, 4, 5]},
    {"deviceID": 1,
     "capturedPower": [10051, 10052, 10053, 10054, 10055, 10056],
     "siteConditionID": [0, 1, 2, 3, 4, 5]}
    ],
    "array_velocity_field": [
    {"deviceID": 0,
        "hub_velocity": [2.75016301683056, 2.5133814393838345, 2.51338143
93838345, 2.3600507858955155, 2.29760598385362, 2.116560480963553],
        "siteID": [0, 1, 2, 3, 4, 5]},
    {"deviceID": 1,
        "hub_velocity": [2.75016301683056, 2.5133814393838345, 2.51338143
93838345, 2.3600507858955155, 2.29760598385362, 2.116560480963553],
        "siteID": [0, 1, 2, 3, 4, 5]}
    ],
    "rotor_diameter": 20
}
```


MACHINE CHARACTERISATION INPUT DATA

Information about the machine technology must be included in the json file. The parameters will depend on the complexity level and technology of the device.

For wave technology:

- "technology": "WEC",
- "complexity": 1, 2 or 3
- "pto_damping": damping of the device. It will be a unique value in complexities 1 and 2. In complexity 3, it is a 6x6 matrix with zeros in all the positions except for the degrees of freedom of the device. In those positions, the value of the PTO damping for each degree of freedom will appear. The value is given in N·s/m

Examples of wave technology can be found below.

```
{
    "technology": "WEC",
    "complexity": 1,
    "id": 3,
    "pto_damping": [1600000]
}
```

In case of complexity 3, pto_damping will appear as follows for a device with 3 degrees of freedom:

```
"pto_damping": [[548000, 0, 0, 0, 0, 0], [0, 548000, 0, 0, 0, 0],[0, 0, 5
48000, 0, 0, 0], [0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0,
0]]
```

For tidal devices, more complex parameters are needed for the identification of the machine:

- "technology": "TEC",
- "complexity": 1, 2 or 3
- "cp": power coefficient of the device
- "number_rotor": number of rotos of the tidal device

In the case of complexities 2 and 3, the following inputs are also needed.

- "tip_speed_ratio": 1,
- "ct": is the inverse of the rotational speed of the device.
- "cut_in_velocity": velocity at which the device starts generating
- "cut_out_velocity": velocity at which the device stops generating

Only in complexity 3, this last input is needed.

- "cp_ct_velocity": hub velocity reference values for each cp and ct inputs given. In m/s

Examples of the json files are shown below for Tidal technology:

```
{
    "technology": "TEC",
    "complexity": 1,
    "id": 3,
    "cp": 0.3,
    "number_rotor": 3
}
```

For complexity 3, more than one sea state can be considered:

```
{
    "technology": "TEC",
    "complexity": 3,
    "id": 3,
    "cp": [0, 0.3, 1, 1, 0.5, 0],
    "number_rotor": 3,
    "tip_speed_ratio": 1,
    "ct": [0, 0.3, 0.3, 0.3, 0.5, 0],
    "cut_in_velocity": 1,
    "cut_out_velocity": 10,
    "cp_ct_velocity": [0, 0.5, 1, 2, 5, 10]
}
```

7.6 ENERGY DELIVERY (ED)

This is the User manual for the energy delivery module within the DTOceanPlus 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 to be added here.
- 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 Energy Delivery module is used to design the electrical infrastructure to transmit power from one or more ocean energy convertors back to shore. It is one of the Deployment Design Tools, run after Energy Capture and Energy Transformation and before Station Keeping. Link to main manual section on the suite of tools.

7.6.1 Overview of the ED Functionalities

The main purpose of the Energy Delivery module is to design the electrical network to transmit power from devices to shore, including the:

- Array network – cables between Ocean Energy Convertors (OEC)
- Collection point (CP), which can be a substation with voltage transformation or a passive hub.

- Transmission cable to the Onshore Landing Point (OLP)

The design is based on User choices, design parameters from other modules, and a catalogue of typical electrical components.

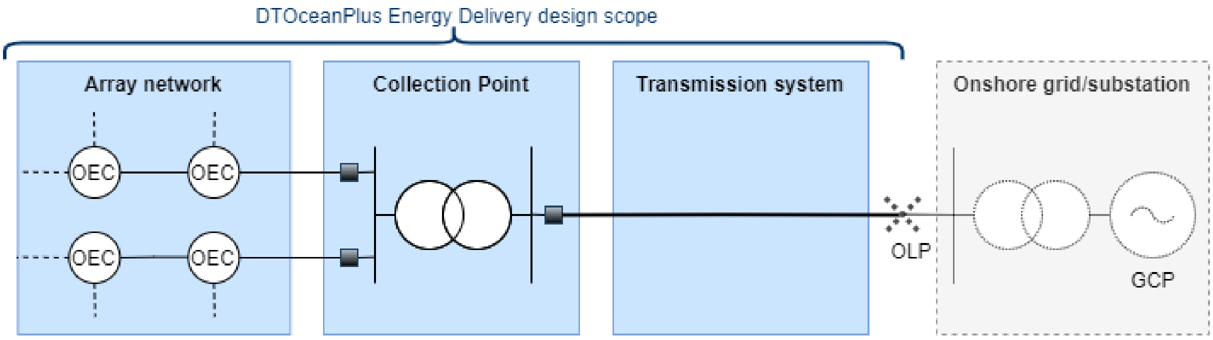


FIGURE 7.15: SIMPLIFIED GENERIC OFFSHORE ELECTRICAL NETWORK FOR OCEAN ENERGY ARRAYS

The main outputs are a network design, the energy and power delivered to shore and network losses, a total cost and bill of materials for the electrical components used, plus a hierarchy of how they are connected.

The module can either be run in simplified mode (complexity 1) or full detail mode (complexity 2/3). Note there is no difference in the design process between complexity 2 and 3, but these have been retained for consistency with other tools. This also allows the user to select a medium complexity level (2) if they are using surrogate data, for example, flat bathymetry.

7.6.2 Workflow for using the ED module

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

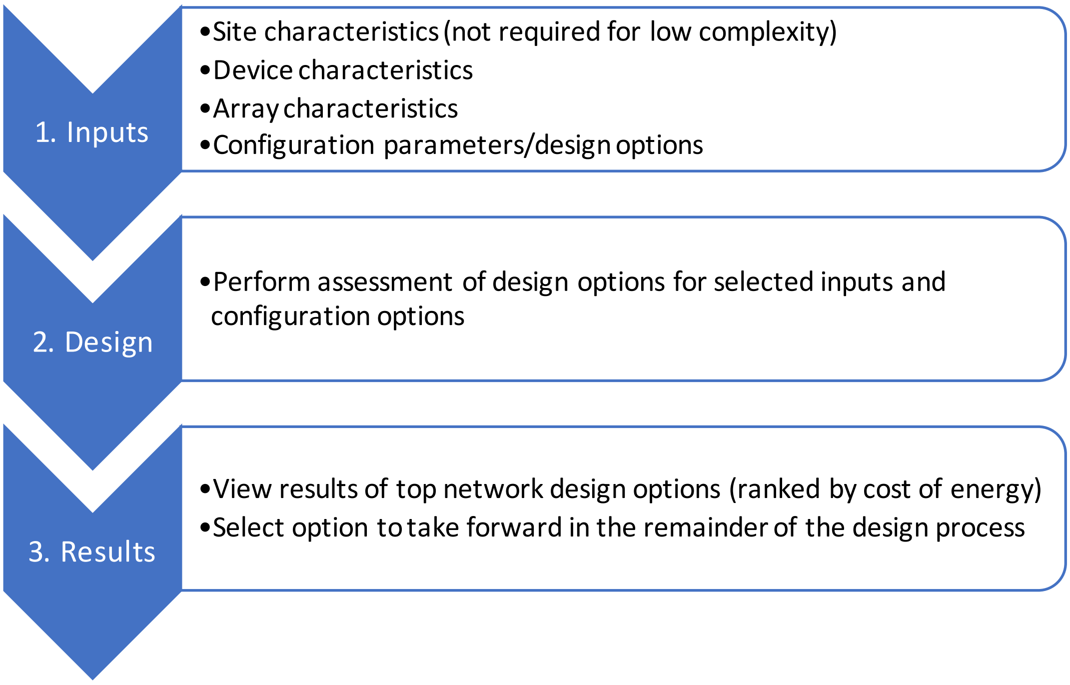


FIGURE 7.16: THE WORKFLOW FOR USING THE ENERGY DELIVERY MODULE

7.6.3 Overview of ED data requirements

This section summarises the types of input data required to run the Energy Delivery 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, the required inputs will all come from other modules except for the onshore landing point co-ordinates and network topology to be assessed.

TABLE 7.38: SUMMARY OF REQUIRED INPUTS

Section	Low complexity	Full complexity
Site characteristics	–	▫ Bathymetry data and seabed material for both lease area and export cable corridor
Device characteristics	▫ Device rated power (kW) ▫ Device rated voltage (V)	▫ Device technology: fixed/floating ▫ Device rated power (kW) ▫ Device rated voltage (V)
Array characteristics	▫ Number of devices ▫ Array spacing (m) ▫ Distance to shore (m) ▫ Onshore distance (m)	▫ Coordinates of onshore landing point ▫ Layout of devices in array as a json string of device coordinates (m, m) ▫ Frequency of occurrence of array power output

Configuration parameters	▫ Onshore infrastructure flag	▫ Network configuration to be assessed

TABLE 7.39: SUMMARY OF OPTIONAL INPUTS

Section	Low complexity	Full complexity
Device characteristics	–	▫ Device connector type: wet-mate/dry-mate ▫ Footprint radius ▫ Device power factor ▫ Location of device electrical connection, as (x, y, z) relative to device (m, m, m) ▫ Device equilibrium draft without mooring system (m)
Array characteristics	▫ Onshore infrastructure cost ▫ Array AEP ▫ Capacity factor	▫ Cost of the onshore infrastructure, for use in LCOE calculation (€) ▫ Electrical losses of onshore infrastructure, percentage of annual energy yield ▫ Max/min voltage allowed in the offshore network (V)
Configuration parameters	–	▫ Predefined export system voltage ▫ Maximum number of devices per string in radial configuration ▫ Predefined burial depth of the array cable(s) and export cable ▫ Maximum seabed gradient considered by the cable routing analysis ▫ Cable installation tool ▫ Cable protection option ▫ Maximum horizontal offset of device for umbilical design

TABLE 7.40: TYPES OF ELECTRICAL COMPONENTS IN CATALOGUE

Category	Subcategory
Cables	▫ Static cables ▫ Dynamic (umbilical) cables
Connectors	▫ Wet-mate ▫ Dry-mate
Collection Points	▫ Collection point ▫ Transformers

7.6.4 ED Tutorials

7.6.4.1 Creating a new Energy Delivery study in standalone mode

Once logged into the server, the first step is to create a new study within the Energy Delivery module.

1. In the left menu, select 'Energy Delivery Studies' and click 'Create an Energy Delivery study'.

2. Fill in an appropriate name and description to identify your study, then select the appropriate complexity level. Complexity level 1 can be used to get a quick estimate with minimal inputs. Complexity levels 2 & 3 are the same and require additional input data parameters such as site bathymetry.
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.

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

7.6.4.2 Using Energy Delivery at low complexity in standalone mode

To get a quick estimate of the costs and efficiency of the electrical infrastructure, use the low complexity (level 1) version of the Energy Delivery module. This assumes the devices are connected in radial to a collection point and does not consider the exact array layout nor the site bathymetry.

1) If required, create a new complexity level 1 study, as described in tutorial 2.
2) From the list of studies, click 'Open' to start working on the complexity level 1 study
3) Click 'Create' under Device inputs to open the page to fill in the device details
   a) Enter the Device rated power (kW) [*required*]
   b) Select the Device rated voltage (V) from the list of typical values [*required*]
   c) Click "Create"
   d) If successful, you will get a message "Device inputs added"
4) Click 'Create' under Array inputs to open the page to fill in approximate details of the array
   a) Enter the number of devices [*required*]
   b) Enter the array spacing (m) [*required*]
   c) Enter the distance to shore (m), defined as the straight-line distance from the cable onshore landing point to the nearest device in the array [*required*]
   d) Enter the onshore cable distance (m), which is the distance between the onshore landing point to the onshore substation [*required*]
   e) Optionally enter the cost of onshore infrastructure costs (onshore substation and cabling). Enter the actual cost of the onshore infrastructure if known beforehand or leave empty to use a cost function that estimates the cost based on the length of the onshore cable required and the power level of the array.
   f) Optionally enter ***either*** the Array Annual Energy Production (AE) (kWh) ***OR*** the average Array capacity factor (%). If neither of these parameters is provided, a capacity factor of 0.3 is assumed by default.
   g) Click "Create"
   h) If successful, you will get a message "Array inputs added"
5) Click 'Create' under Cable configuration inputs to open the page to fill in the configuration details
   a) Select whether to include the onshore infrastructure cost or not in the analysis [*required*]
   b) Click "Create"
   c) If successful, you will get a message "Configuration inputs added"

6) To view the device, array or configuration inputs click "View/Update/Delete" under the appropriate input type.
7) To update any of the device, array or configuration inputs, click "View/Update/Delete" under the appropriate input type. On the update page, only input the parameters that need to be modified. Click 'Update' after making the updates.
8) To delete the device, array or configuration inputs, click "View/Update/Delete" under the appropriate input type. Click 'Delete', which will produce a pop-up window asking for confirmation. Click 'Delete' again to delete the inputs from the database.
9) To run the assessment, click the 'Perform ED system design and analysis', which should only take a few seconds at complexity level 1. An alert window informs when this is complete. Click 'view results' to see a summary of the design.
10) The following summary parameters are presented for simplified network design

    - Configuration: *always radial in simple complexity*
    - Annual energy yield: kWh
    - Annual losses: kWh
    - Annual efficiency: %
    - Array power output: kW
    - Total cost: €
    - Cost of energy (electrical): €/kWh

    There is no network schematic for the low complexity mode.

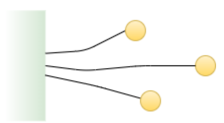
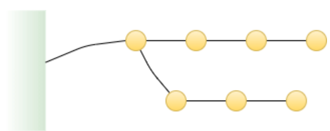
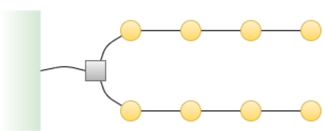
7.6.4.3 Using Energy Delivery at medium/high complexity in standalone mode

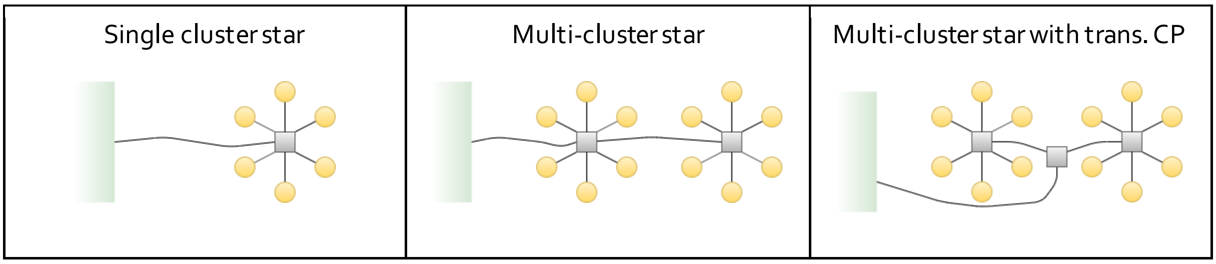
To perform a more detailed design of the electrical infrastructure, use the full complexity (level 2 or 3) version of the Energy Delivery module. There is no difference in the inputs required or the calculation process between levels 2 and 3, however, it is suggested level 2 is selected where surrogate data such as a flat bathymetry is used to indicate this is a lower detail calculation.

1) If required, create a new complexity level 2 or 3 study, as described in tutorial 2.
2) From the list of studies, click 'Open' to start working on a complexity level 2 or 3 study
3) Click 'Create' under Site inputs to open the page to fill in the site bathymetry details
    a) Upload two data files for the site lease area and export area (cable corridor) in json format [*both required*]. See the how-to guide for details of the format.
    b) Click "Create"
    c) If successful, you will get a message, "Site inputs added". Note that for large bathymetry files, it can take a while before the successful message is displayed.
4) Click 'Create' under Device inputs to open the page to fill in the device details
    a) Select the type of technology (fixed/floating) [*required*]
    b) Enter the Device rated power (kW) [*required*]
    c) Select the Device rated voltage (V) from the list of typical values [*required*]
    d) Optionally select the Device connector type (wet-mate / dry-mate). Wet-mate assumed by default

e) Optionally enter a Footprint radius (m). This is the radius of the circle around a device considered as an exclusion zone for cable routing, 25m assumed by default.
f) Optionally enter the Power factor (-). This is a measure of the ratio between the real and reactive power output of a device. It normally has a value between 0.9 and 1.0, with 1.0 used by default.
g) Optionally enter the Umbilical connection point (m, m, m), which is the location of the electrical connection as (x, y, z) coordinates in the local (device) coordinate system. Please ensure that there are no whitespaces in the input. (0,0,0) used by default.
h) Optionally enter the Equilibrium draft (m). 0m is used by default.
i) Click "Create"
j) If successful, you will get a message "Device inputs added"

5) Click 'Create' under Array inputs to open the page to fill in details of the array configuration
   a) Enter the cable landing point co-ordinates [*required*], which are the UTM co-ordinates (m east, m north) of the point at which the export cable reaches the shore.
   b) Copy in the Array device layout in json format [*required*]. See how-to guide for details of the format.
   c) Enter the Frequency of occurrence of array power output (%) [*required*]. This is the frequency of occurrence of the ten array power output levels [10,20,30,40,50,60,70,80,90,100] percent of rated power in the following format: e.g. [0.1,0.2,0.2,0.1,0.05,0.05,0.05,0.05,0.1,0.1]. The values should add up to 1.0. Please ensure that there are no whitespaces in the input.
   d) Optionally enter a lump-sum Onshore infrastructure cost (€). This includes the cost of any cables/overhead lines between the onshore landing point and the nearest onshore substation. Enter the actual cost of the onshore infrastructure if known beforehand or enter 0 to exclude this cost from the analysis.
   e) Optionally enter the Onshore losses (%). These losses are added to the network losses, as a percentage of the network losses, after the evaluation of the network losses using a power flow solver. Default is 0%.
   f) Optionally enter the Maximum voltage limit and Minimum voltage limit (p.u.). Network designs that cause the network voltage to go beyond the defined range between the maximum and the minimum voltage limits will be considered to be technically unfeasible. Default limits are 1.1 and 0.9, respectively.
   g) Click "Create"
   h) If successful, you will get a message "Array inputs added"
6) Click 'Create' under Cable configuration inputs to open the page to fill in the configuration details
   a) Select the Network configuration to be assessed from the following options [*required*]

Direct to shore	Radial	Radial with transmission CP
		

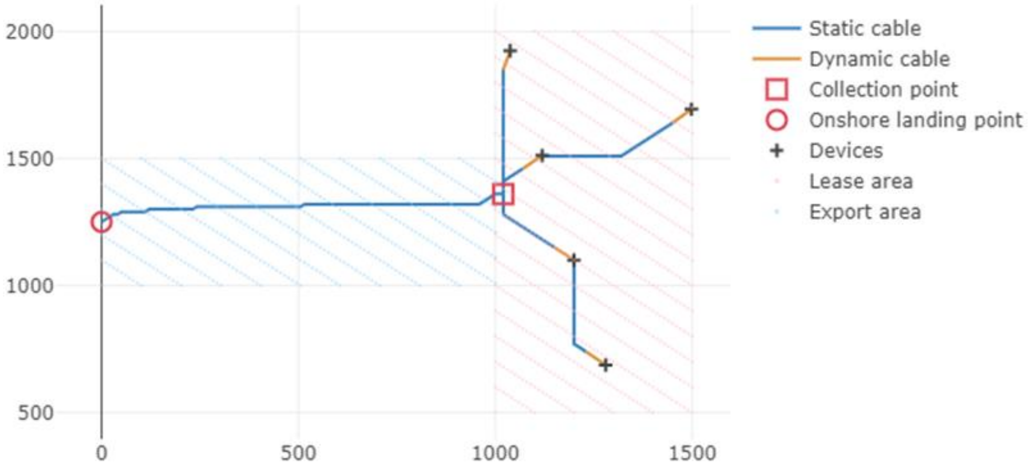


    b) Optionally select the Export Voltage (V) from the list of options. Optimal export voltage calculated if omitted.
    c) Optionally enter the Maximum number of devices per string in radial network
    d) Optionally enter a Target burial depth for array cables (m) and the export cable (m). Input a target burial depth of 0 m for cables laid on the seabed. The target burial depth will be ignored if the cable installation tool selected is "Seabed lay".
    e) Optionally enter a Cable installation equipment gradient constraint (degrees from horizontal). No constraint (90 degrees) used by default.
    f) Optionally select a Cable installation method. Not selecting a cable installation tool allows the optimal method for the seabed type to be selected.
    g) Optionally select a Cable protection option. This is relevant only when either the array or export cables are seabed laid (i.e. have a target burial depth of 0 m).
    h) Optionally enter the maximum horizontal offset of the device (m). This parameter is associated with umbilical design for floating devices.
    i) Click "Create"
    j) If successful, you will get a message "Configuration inputs added"

7) To view the site, device, array, or configuration inputs, click "View/Update/Delete" under the appropriate input type.
8) To update any of the sites, device, array, or configuration inputs, click "View/Update/Delete" under the appropriate input type. On the update page, only input the parameters that need to be modified. Click 'Update' after making the updates.
9) To delete the site, device, array, or configuration inputs, click "View/Update/Delete" under the appropriate input type. Click 'Delete', which will produce a pop-up window asking for confirmation. Click 'Delete' again to delete the inputs from the database.
10) To run the assessment, click the 'Perform ED system design and analysis' which may take several minutes depending on the number of devices and/or bathymetry points. An alert window informs when this is complete. Once this is complete click 'view results'.
11) The following summary parameters are presented for the top three network designs (selected based on the lowest cost-of-energy for the electrical components).

    - Configuration: (topology)
    - Annual energy yield: kWh
    - Annual losses: kWh
    - Annual efficiency: %
    - Array real power output: kW
    - Array reactive power output: kVAr
    - Total cost: €

- Cost of energy (electrical): €/kWh
- Network schematic (example below)



12) Optionally review the more detailed information provided on each of the network design options.

[Note that when the tool is running in integrated mode with the other modules, the User will select one network to take forward for further design and analysis. This feature is not yet implemented.]

7.6.5 ED How-to Guides

7.6.5.1 How to prepare data for using the Energy Delivery module

This guide summarises the data requirements and specifications for running the Energy Delivery module in full complexity standalone mode but notes which parameters are not required at low complexity and which come from other modules in integrated mode.

FORMAT THE BATHYMETRY DATA FOR SITE LEASE AREA AND EXPORT CABLE CORRIDOR

For full complexity (2/3) only, not considered in complexity 1.

The bathymetry should be provided as two json files, for the site lease area and export cable corridor. These files should be a rectangular grid containing water-depth and surface soil type, formatted as UTM co-ordinates (m easting, m northing). The following fields should be included:

- "id" – a sequential list of grid point ID numbers, starting at 0.
- "i" – index value for x points
- "j" – index value for y points
- "x" – ordered list of X coordinates of grid points (m east)
- "y" – ordered list of Y coordinates of grid points (m north)
- "layer 1 start" – ordered list of Z coordinates of grid points (m). Note that positive is upwards, therefore water depths are negative.
- "layer 1 type" – ordered list of soil types of grid points.

A short example is shown below:

```
{"lease_bathymetry": {
    "id": [0, 1, 2, 3, 4, 5, …],
    "i": [0, 0, 0, 1, 1, 1, …],
     "j": [0, 1, 2, 0, 1, 2, …],
      "x": [1000, 1000, 1000, 1020, 1020, 1020, …],
     "y": [500, 510, 520, 500, 510, 520, …]
    "layer 1 start": [-50, -50, -50, -50, -51, -52, …],
     "layer 1 type": ["loose sand", "loose sand", "loose sand", "dense
 sand", "soft clay", "hard clay", …],
}}
```

7.7 STATION KEEPING (SK)

This is the User manual for the Station Keeping 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 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 Station Keeping module is used to design and assess the mooring system, anchors and foundations of the devices and substation. It is one of the Deployment Design Tools, run after Energy Delivery and before Logistics & Marine Operations.

7.7.1 Overview of the SK Functionalities

The main purpose of the Station Keeping module is to design and assess the mooring system, anchors and foundations of the devices and substation, including (see Figure 7.17):

- Mooring lines for floating structure (design, ULS analysis and FLS analysis)
- Anchors (design and ULS analysis)
- Foundation for fixed structure (design and ULS analysis)

The design is based on User choices and inputs, design parameters from other modules, and a catalogue of typical line types and anchors.

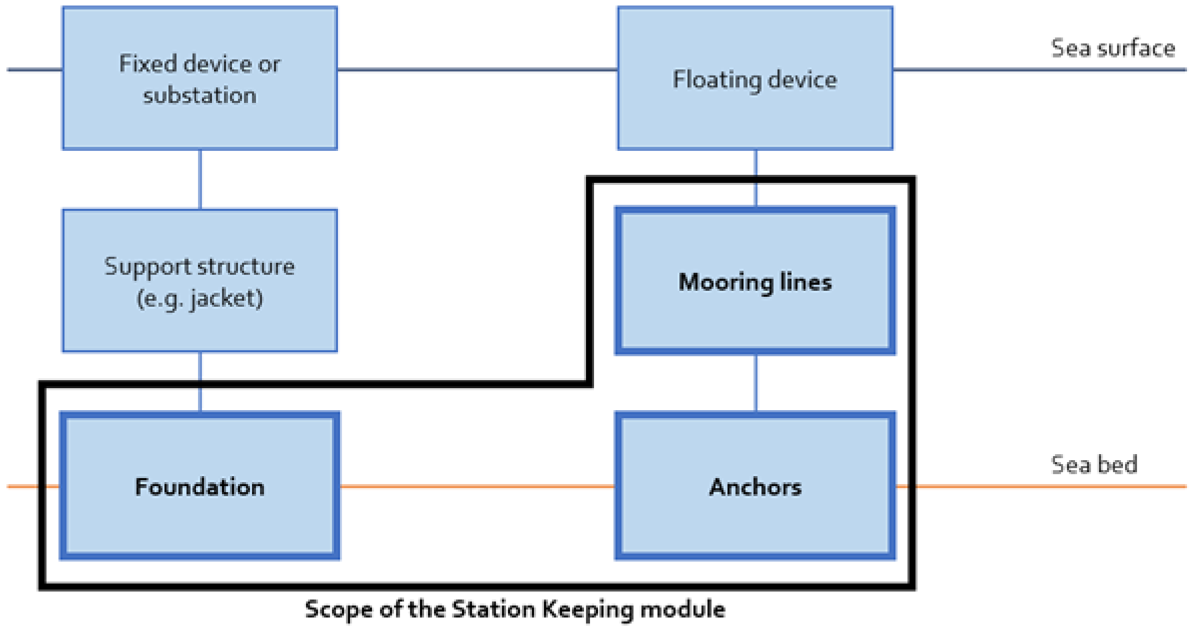


FIGURE 7.17: SCOPE OF THE STATION KEEPING MODULE

The main outputs are the assessment of the mooring system, foundation and anchor design, the total cost and bill of materials for the components used, a hierarchy of how they are connected.

The module can either be run in simplified, medium or advanced mode (complexity level 1, 2, or 3). The level of details of inputs increases with the level of complexity. For example, at low levels of complexity (1 and 2), it is proposed to the User to let the SK module automatically define suitable dimensions of the mooring system, anchors and foundations.

7.7.2 Workflow for using the SK module

The workflow for using the Station Keeping module can be summarised as 1) provide inputs, 2) run the design analysis, and 3) view the results, as shown in Figure 7.18.

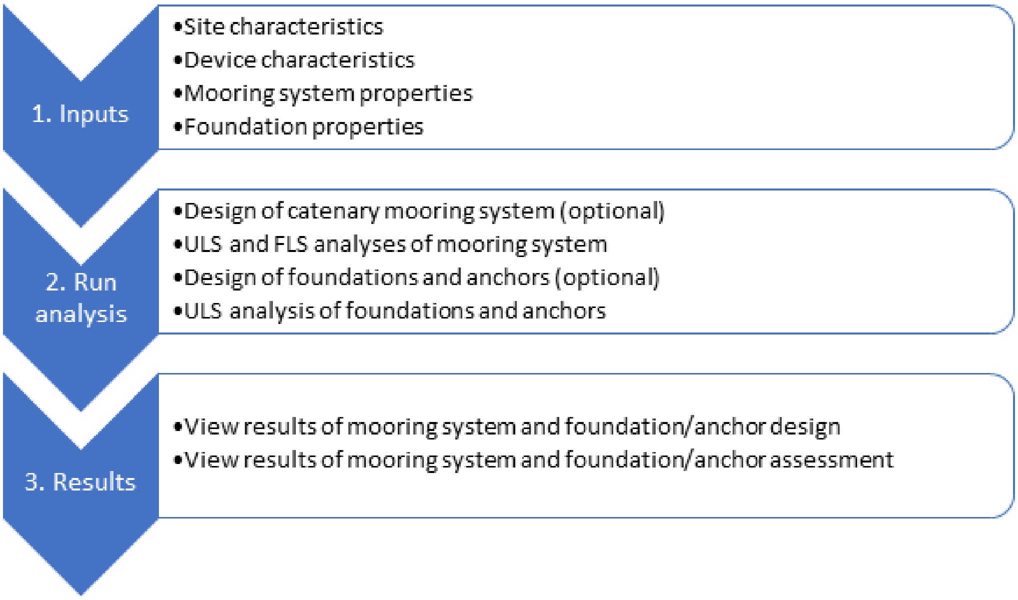


FIGURE 7.18: THE WORKFLOW FOR USING THE STATION KEEPING MODULE

7.7.3 Overview of SK data requirements

This section summarises the types of input data required to run the Station Keeping module.

The required inputs to run the module are summarised in Table 7.41. Note that in integrated mode, these all come from other modules except for the mooring, anchor and foundation properties.

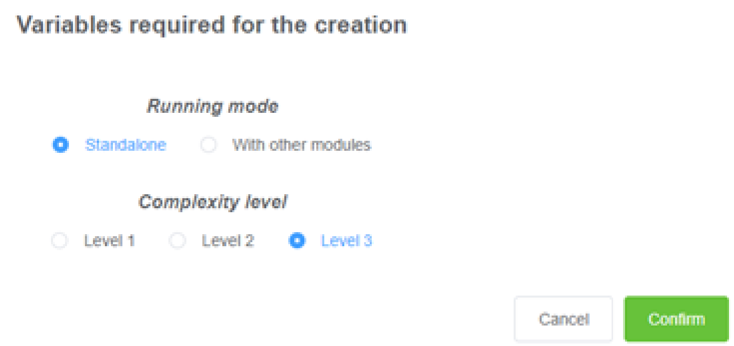
TABLE 7.41: SUMMARY OF REQUIRED INPUTS

	Full complexity
Site characteristics	▫ Sea states statistics ▫ Wind statistics ▫ Current statistics ▫ Bathymetry
Device characteristics	▫ Main dimensions ▫ Hydrostatic data ▫ Hydrodynamic data ▫ If tidal, rotor characteristics
Array characteristics	▫ Layout of devices
Mooring system properties	▫ Mooring lines properties ▫ Mooring lines layout
Foundation / anchors properties	▫ Foundation / anchor type ▫ Foundation / anchor main dimensions

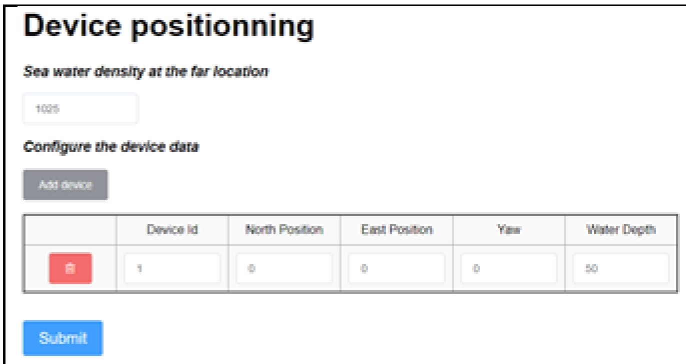
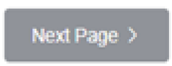
7.7.4 SK Tutorials

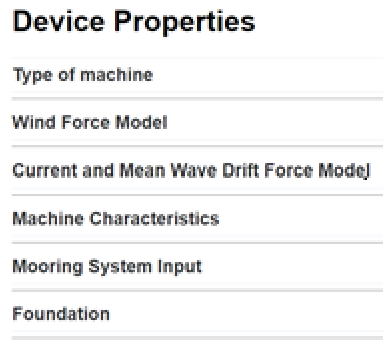
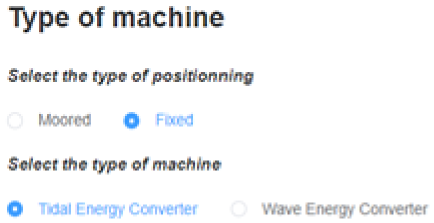
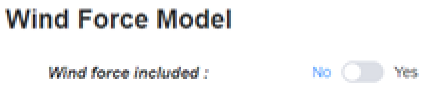
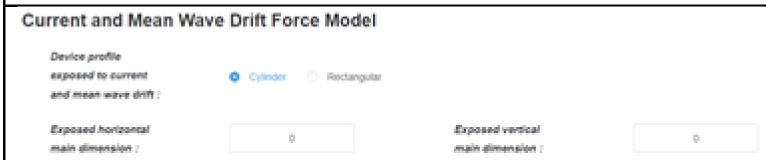
7.7.4.1 TUTORIAL NO.1: DESIGNING MONOPILE FOUNDATION OF A FIXED TIDAL MACHINE IN STANDALONE MODE

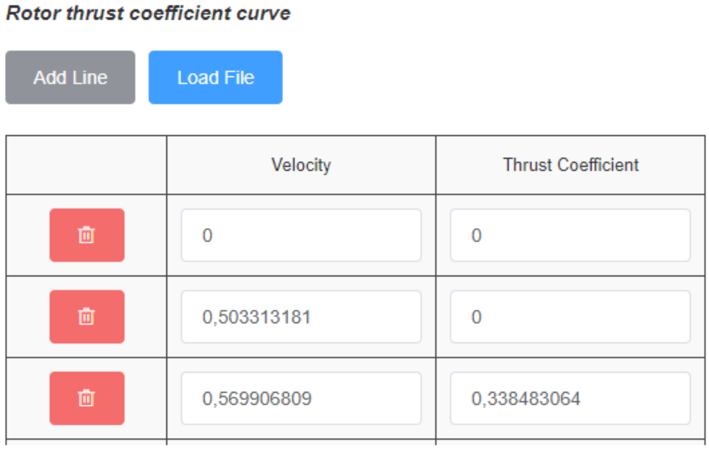
Step 1 : create new project

	Create a new project
	Select 'standalone' running mode and 'complexity level 3' and click on 'confirm'.

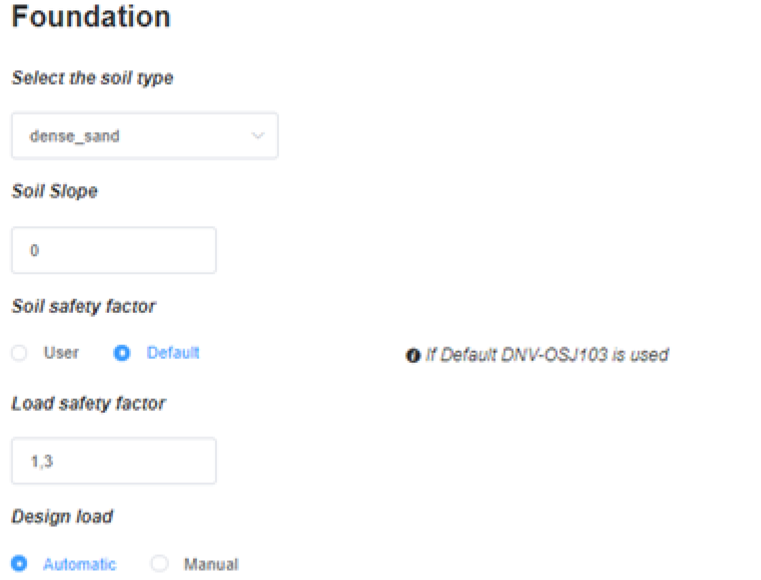
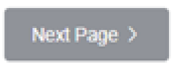
Step 2 : define main device properties

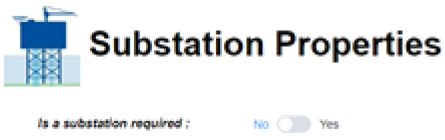
	Enter the water depth where the device is to be installed.
	Click on 'next page'

	We will now have to fill in the data contained in each of the 6 sections of 'Device properties'. Click on each section to expand or collapse it. We start by clicking on the first section: 'Type of machine.'
	In the section 'type of machine', select 'Fixed' and 'Tidal Energy Converter' as the considered device is a tidal machine fixed on the seabed.
	A submerged machine is not exposed to wind.
	No current forces, and no mean wave drift forces are applied here. Forces on rotor are defined separately, in the 'Machine Characteristics' section.
	In the following, we will fill the section 'Machine characteristics'
	Enter the mass of the device only, not including the foundation (since finding the mass of the foundation is the goal of the present analysis).

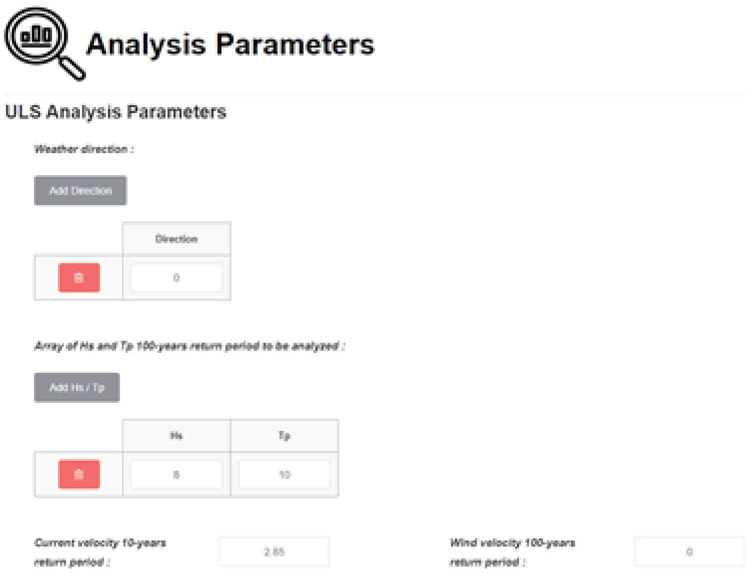
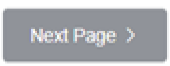
	Populate the table to describe the rotor thrust coefficient file. As an alternative, click on 'Load file' and enter the file path that contains the rotor thrust coefficient curve. The values will be loaded in the table to check that the file has been interpreted correctly.
	Enter the rotor diameter, and specify the position of the two rotors relative to the seabed level. If the device was floating, this would be relative to the free surface level.

Step 3 : define foundation analysis parameters

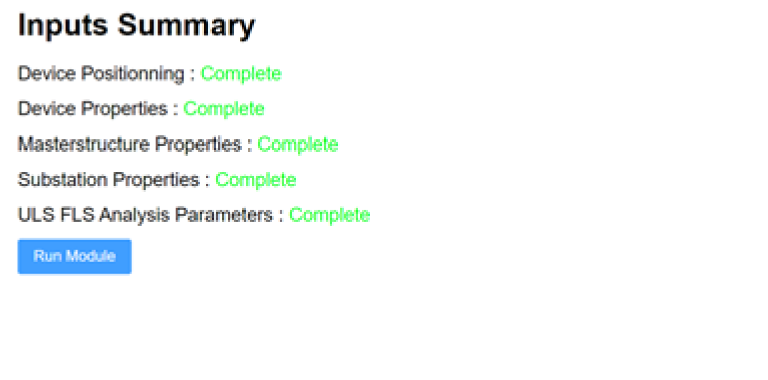
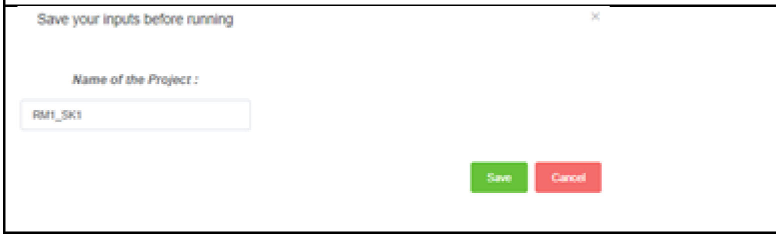
<table>
<tr><td>
</td><td>In the section ‘Foundation’, define the soil type (e.g. dense sand). If we assume that the seabed is flat, the soil slope is 0. We can use the default soil safety factor, and we set the load safety factor equal to 1.3 (which is the default value).</td></tr>
<tr><td>
</td><td>Choose Manual’ for ‘Foundation type selection’, and ‘Pile’ as ‘Foundation preference’. The SK module will be forced to consider a foundation of type ‘Pile’. Let the ‘Dimensioning method’ be ‘Automatic’ so that SK module will compute the suitable dimensions. The maximum deflection criteria are commonly 5% for fixed structure. Define the pile end tip and length of the pile above seabed.</td></tr>
<tr><td>
</td><td>Click on ‘next page’</td></tr>
</table>

Masterstructure not present	A master structure model is used when several floating devices are moored together. This is not the case here.
	In our case, we do not want to define a substation. Select 'No'. Click on 'Next page'.

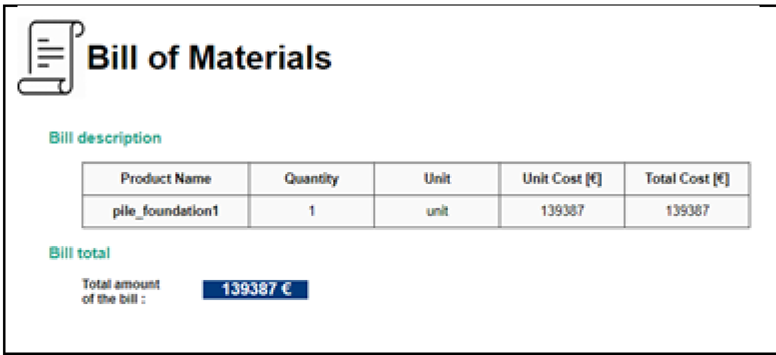
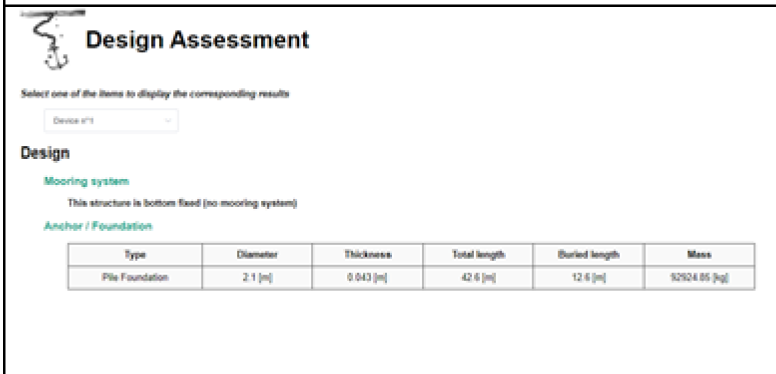
Step 4 : define ULS analysis parameters

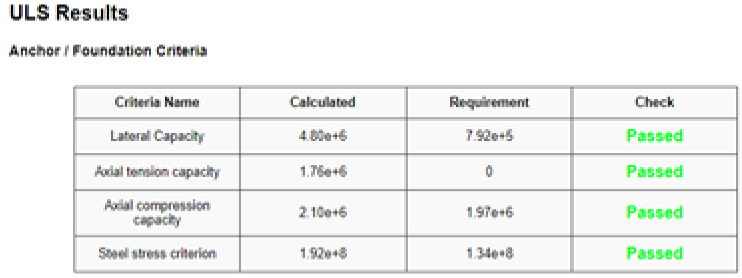
	Set the weather direction to zero. This does not matter much here because we always assume that the rotor faces the current. Define the Hs and Tp: their value will be used to compute a water particle velocity which will be added to the current velocity in order to compute drag forces on the pile foundation. For the forces on the rotors, however, this does not change anything since only the velocity from the current is used. Set the current velocity value. Set the wind velocity to zero, since we are not interested in wind.
	Click on 'next page'

Step 5 : run analysis

<table>
<tr>
<td>
</td>
<td>We are now on the 'run' page. The summary of the inputs shows if each section has been validated ('complete') or if some are missing ('incomplete'). At this point everything should be 'complete'. Click on 'Run module'.</td>
</tr>
<tr>
<td>
</td>
<td>You are asked to save your project. Enter a name for the project and click on 'Save'.</td>
</tr>
</table>

Step 6 : results

<table>
<tr>
<td>
</td>
<td>In the 'Bill of Materials' page, the estimated cost of the pile foundation shown. This corresponds to the cost of the whole pile.</td>
</tr>
<tr>
<td>
</td>
<td>In the 'Design Assessment' page, the dimensions of the Pile foundation are displayed: diameter buried length and thickness.</td>
</tr>
</table>



ULS Results

Anchor / Foundation Criteria

Criteria Name	Calculated	Requirement	Check
Lateral Capacity	4.80e+6	7.92e+5	Passed
Axial tension capacity	1.76e+6	0	Passed
Axial compression capacity	2.10e+6	1.97e+6	Passed
Steel stress criterion	1.92e+8	1.34e+8	Passed

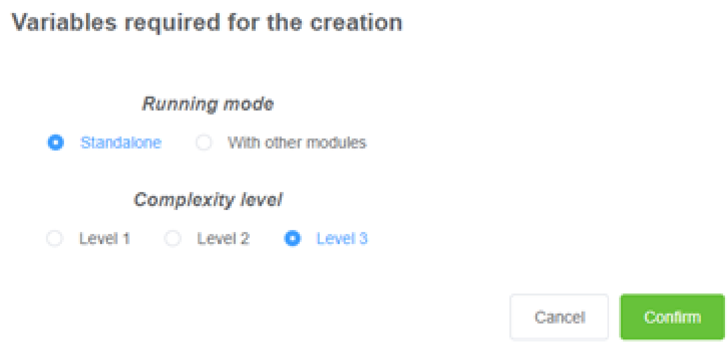
On the 'ULS/FLS' page, we can check that the four criteria required for a pile foundation are validated for the ULS condition that we have specified.

In a situation where we already know the dimensions of the pile which we would like to use, we can use the SK module to check the criteria for the dimensions of the pile foundation. To do that, in the 'Foundation' section, set the 'Dimensioning method' as 'Manual', enter the dimensions of the monopile and rerun the tool.

7.7.4.2 TUTORIAL NO.2: ASSESSING MOORING SYSTEM OF A WAVE ENERGY CONVERTER IN ULTIMATE LIMIT STATE CONDITIONS IN STANDALONE MODE

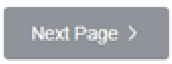
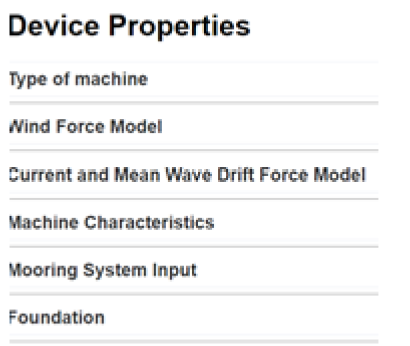
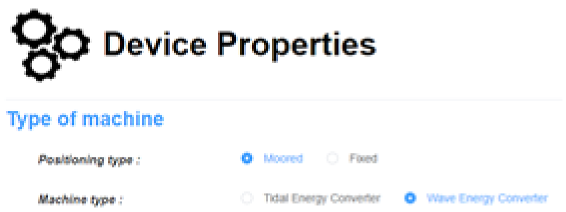
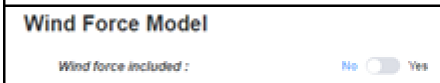
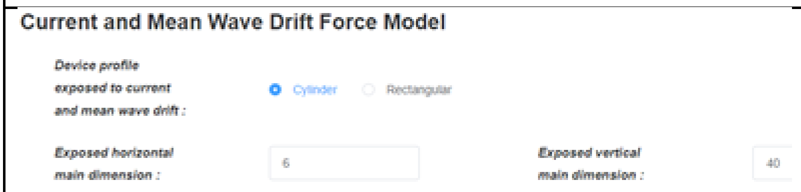
Step 1 : create new project

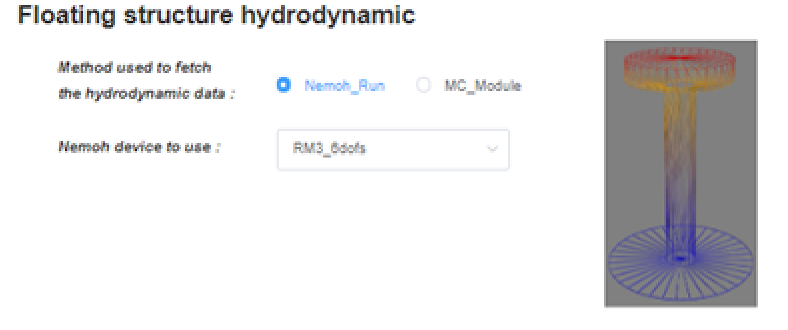
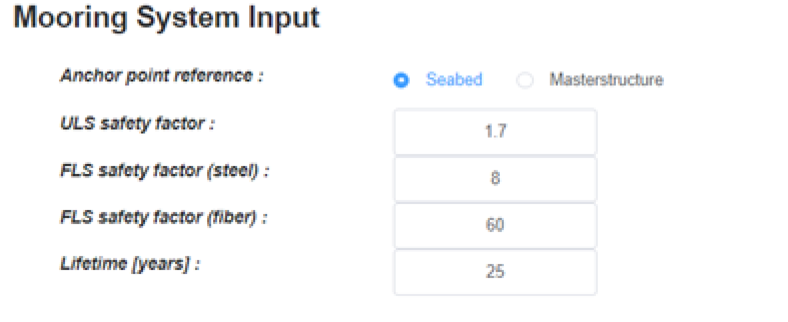
Create a new project

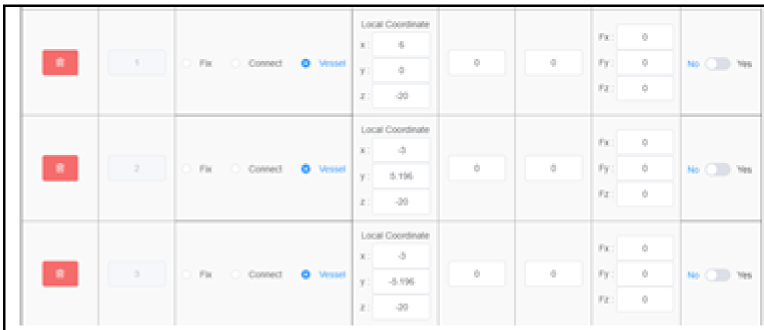
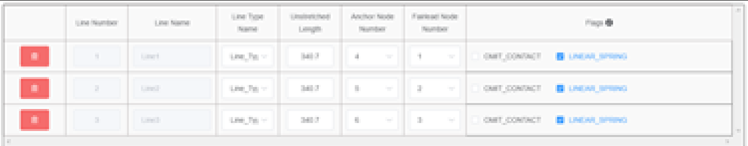


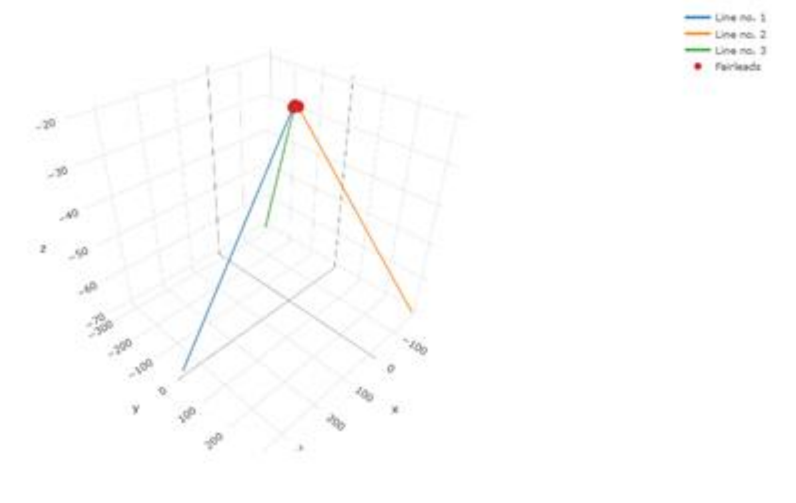
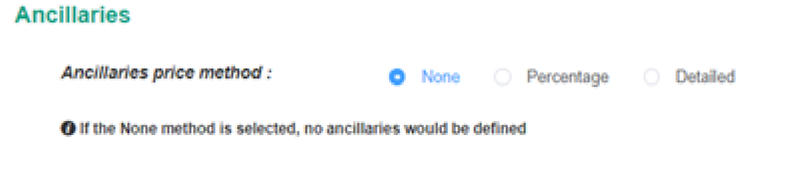
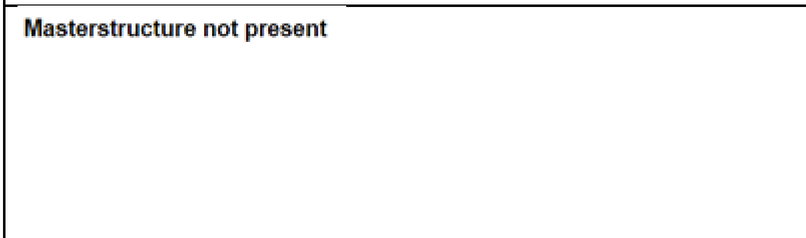
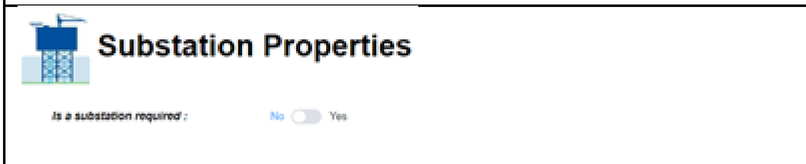
Select 'standalone' running mode and complexity level3 and click on 'confirm.'

Step 2 : define main device properties

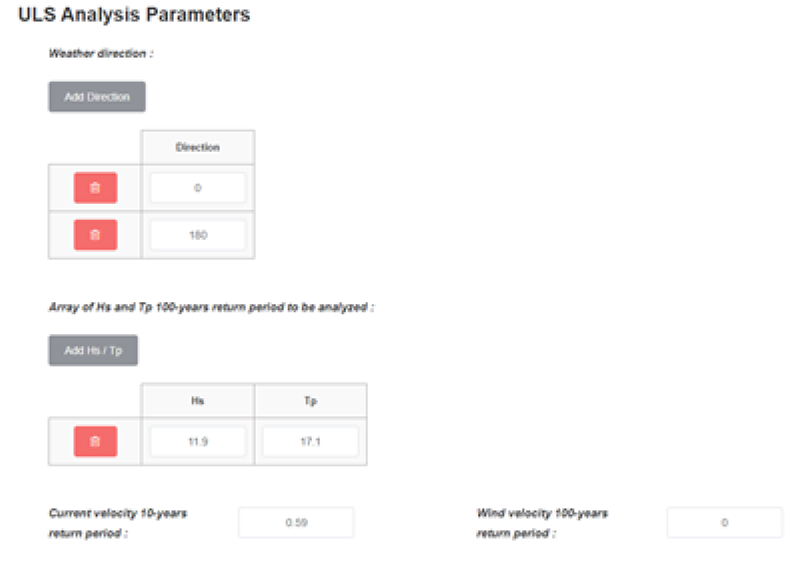
	Enter water depth where the device is to be installed.
	Click on 'next page'
	We will now have to fill the data contained in each of the 6 sections of 'Device properties'. Click on each section to expand or collapse it. We start by clicking on the first section: 'Type of machine'
	In the section 'type of machine', select 'Moored' and 'Wave energy converter'.
	We assume that we will neglect the wind forces.
	Enter the dimensions of the main structure exposed to current and mean wave drift forces.

	Select 'Nemoh_Run' as a source of hydrodynamic data, as we have not run the DTO+ Machine Characterization (MC) module (we are in standalone mode). Select a default machine (e.g. 'RM3_6dofs'). The hydrodynamic data contains linear diffraction and radiation coefficients.
	The desired mooring system is to be anchored on the seabed. We use default safety factors. We assume lifetime as 25 years.
	On the page 'Device properties', in the section 'Mooring system input', select the 'Custom' mooring system definition method.
	Click on the 'Define' Button to open the custom mooring system wizard. We will use this wizard to define a taut system with 3 nylon lines.
	Define one line type: browse in the 'catalogue_id' list and select a nylon rope diameter.

	Define 3 fairlead nodes: node type is 'Vessel' and positions are given in the floater coordinate system.
	Add 3 anchor nodes: node type is 'Fix' and positions are given in Earth-fixed coordinate system. For those nodes, specify that an anchor is required.
	Define 3 lines and specify their length. We define taut lines, so the option 'LINEAR_SPRING' must be selected for each line (so those catenary equations are not used).
	Click on 'Check and plot' button
	Set water depth and Water density and click on 'Confirm'.

	A new page is opened. It contains a 3D plot of the defined mooring system, as well as other data: tension in the lines, mooring forces and mooring stiffness matrix.
	We choose not to define additional ancillaries at this stage.
	We use the default values for the foundation design (which will be anchors in this case). DTO+ will select the most appropriated type of anchor and will design it automatically.
	A master structure model is used when several floating devices are moored together. This is not the case here. Click on 'Next page'.
	In our case, we do not want to define a substation. Select 'No'. Click on 'Next page'.

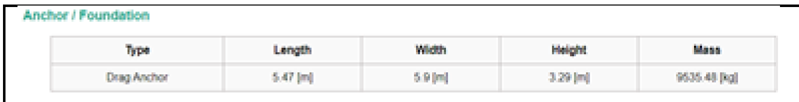
Step 4 : define ULS analysis parameters



Define weather directions for ULS analysis.

Define the ULS condition for waves (Hs, Tp) and current velocity.

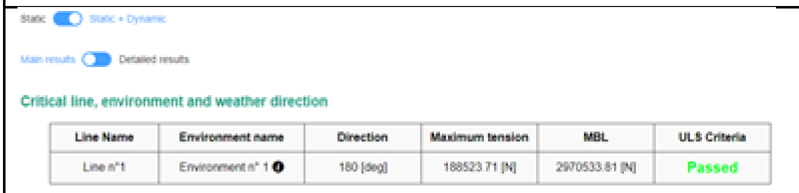
Step 5 : results



Anchor / Foundation

Type	Length	Width	Height	Mass
Drag Anchor	5.47 [m]	5.9 [m]	3.29 [m]	9535.48 [kg]

In the 'Design assessment' page, you can find a summary of the mooring system design, the line pretension, the estimated eigen periods of the floater, the mooring stiffness. You can also find the calculated drag anchor dimensions (9.5 tons).



Critical line, environment and weather direction

Line Name	Environment name	Direction	Maximum tension	MBL	ULS Criteria
Line n°1	Environment n° 1	180 [deg]	188523.71 [N]	2970533.81 [N]	Passed

In the 'ULS/FLS' page, ULS analysis results are available. In particular, in the 'line result' section, if we select 'static+dynamic', we can see that the ULS criteria is passed or not.

7.8 LOGISTICS AND MARINE OPERATIONS (LMO)

The present section is the User manual of the Logistics and Marine Operations module within the DTOceanPlus design 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 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 Logistics and Marine Operations is one module of the DTOceanPlus Deployment Design Tools. This module is responsible for designing logistical solutions for the installation, operation and maintenance (O&M), and decommissioning phases of ocean energy projects. Logistic solutions consist of an operation plan and an optimal combination of vessels, equipment and ports that minimise the costs of each operation individually, reducing capital and operational expenditures simultaneously (CAPEX and OPEX). As the last of the Deployment Design Tools, the LMO module runs after the entire list of design modules, including Machine Characterisation, Energy Capture, Energy Transformation, Energy Delivery, and Station Keeping, receiving inputs from all of these. (Section 1.2.)

7.8.1 Overview of the LMO Functionalities

The main purpose of the Logistics and Marine Operations module is to design logistical solutions for the installation, operation and maintenance (O&M), and decommissioning phases of ocean energy projects. Logistic solutions consist of an operation plan and an optimal combination of vessels, equipment and ports that minimise the costs of each operation individually, reducing capital and operational expenditures simultaneously (CAPEX and OPEX).

For the different project lifecycle phases (installation, O&M, decommissioning), the logistical solutions include:

1. **Infrastructure solutions** – optimal selection of vessels, ports and support equipment to carry out the installation/O&M/decommissioning operations
2. **Operation plans** – operation durations, weather contingencies, start dates, end dates.
3. **Operation costs** – cost of operations, including vessel chartering costs, fuel costs, port costs and equipment costs. These costs grouped into installation, maintenance and decommissioning

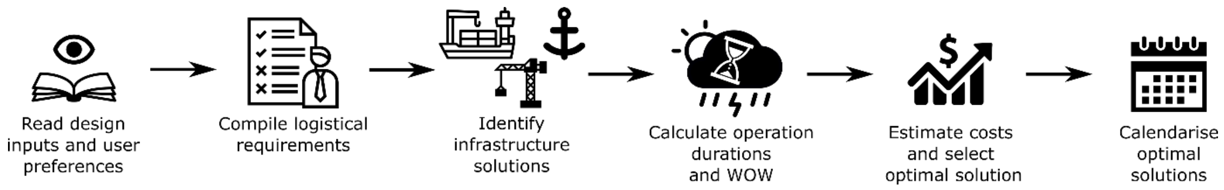


FIGURE 7.19: FUNCTIONALITIES OF THE LMO MODULE

The module can either be run in simplified mode (complexity 1) or full detail mode (complexity 2/3). Note there is no difference in the logistic design process between complexity 2 and 3, but these have been retained for consistency with other tools. For more information on levels of complexity within DTOceanPlus, please see Section 1.2.

7.8.2 Workflow for using the LMO module

The workflow for using the Logistics and Marine Operations module can be summarised as 1) provide the first round of inputs, 2) provide a second round of inputs after first intermediate calculations, 3) perform a design, and 4) view the results, as shown in Figure 7.20.

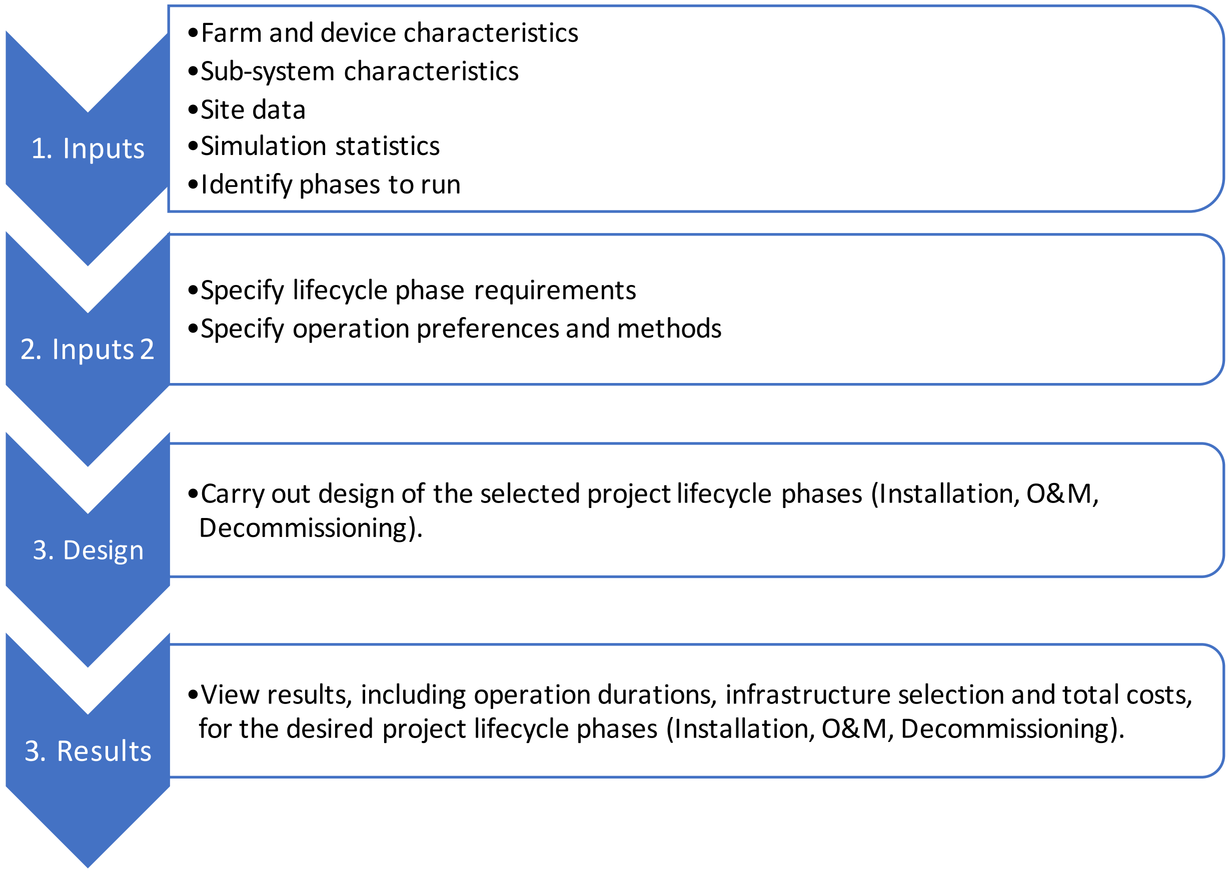


FIGURE 7.20: WORKFLOW OF THE LMO MODULE

7.8.3 Overview of LMO data requirements

This section summarises the types of input data required to run the Logistics and Marine Operations module. Full details and data specifications are given in the how to guide on preparing data (Section 7.8.5).

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

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

TABLE 7.42: SUMMARY OF REQUIRED INPUTS

Input Page	Low complexity (cpx1)	Full complexity (cpx2 & cpx3)
Project inputs	▫ Installation start month (mm/yyyy) ▫ Maintenance start month (mm/yyyy) ▫ Consider device repair at port (Bool) ▫ Device fully submerged (Bool) ▫ Operations maximum wave height (m) ▫ Project lifetime (years)	▫ Installation start date (dd/mm/yyyy) ▫ Maintenance start date (dd/mm/yyyy) ▫ Consider device repair at port (Bool) ▫ Device fully submerged (Bool) ▫ Project lifetime (years)
External inputs	▫ Device type (WEC/TEC) ▫ Device topology (fixed/floating) ▫ Device dimensions (m) ▫ Device mass (kg) ▫ Number of devices ▫ Farm layout ▫ Energy transformation hierarchy ▫ Mass of PTO components ▫ Cost of PTO components ▫ PTO rated power ▫ PTO failure rates ▫ Station keeping hierarchy ▫ Anchor type, number, mass dimensions, soil type, failure rates and costs ▫ Mooring line type, number, mass dimensions, soil type, failure rates and costs ▫ Foundation type, number, mass dimensions, soil type, burial depth, failure rates, and costs ▫ Energy delivery hierarchy ▫ Collection point type, number, mass dimensions, soil type, failure rates and costs ▫ Cable type, length, burial depth, route, soil type, burial method, cable protections, connector type, cable costs	▫ Device type (WEC/TEC) ▫ Device topology (fixed/floating) ▫ Device dimensions (m) ▫ Device mass (kg) ▫ Number of devices ▫ Farm layout ▫ Energy transformation hierarchy ▫ Mass of PTO components ▫ Cost of PTO components ▫ PTO rated power ▫ PTO failure rates ▫ Station keeping hierarchy ▫ Anchor type, number, mass dimensions, soil type, failure rates and costs ▫ Mooring line type, number, mass dimensions, soil type, failure rates and costs ▫ Foundation type, number, mass dimensions, soil type, burial depth, failure rates, and costs ▫ Energy delivery hierarchy ▫ Collection point type, number, mass dimensions, soil type, failure rates and costs ▫ Cable type, length, burial depth, route, soil type, burial method, cable protections, connector type, cable costs
Site inputs	▫ Bathymetry	▫ Bathymetry

	▫ met-ocean timeseries (Hs) ▫ seabed characteristics	▫ met-ocean timeseries (Hs, Ws, Cs) ▫ seabed characteristics
Project lifecycle phases	▫ Installation ▫ Maintenance ▫ Decommissioning	▫ Installation ▫ Maintenance ▫ Decommissioning
Phase requirements	▫ N/A	Installation/Maintenance/Decommissioning phase requirements ▫ Consider ROV/Divers
Operation methods	▫ N/A	▫ Device transportation method ▫ Device load-out method ▫ Pile transportation method ▫ Pile load-out method ▫ Anchors load-out method ▫ Collection point transportation method ▫ Collection point load-out method ▫ Cable burial method ▫ Cable landfall method

TABLE 7.43: SUMMARY OF OPTIONAL INPUTS

Input Page	Low complexity (cpx1)	Full complexity (cpx2 & cpx3)
Project inputs	▫ N/A	▫ Consider device towing draft (Bool) ▫ Device towing draft (m) ▫ Safety factor for vessel selection ▫ Fuel price (€/ton) ▫ Specific Fuel Oil Consumption (g/kWh) ▫ Average vessel load factor ▫ Weather window statistics ▫ Vessel statistics
Phase requirements	▫ N/A	Installation/Maintenance/Decommissioning phase requirements ▫ Disregard ports without: ▫ Previous experience in MRE projects ▫ Insufficient terminal area ▫ Insufficient terminal quay load bearing capacity ▫ Insufficient crane capacity at the terminal ▫ Outside radius from site

7.8.3.1 User inputs from the GUI

The User will set basic information about the LMO study and provide the main project inputs, device and subsystem characteristics, as well as operation methods and preferences, depending on the complexity level and technology.

- **Study**: Name, description, complexity and standalone mode (yes/no)
- **Project inputs**: project installation date, maintenance start date, consider repair at port (yes/no), device towing draft, project lifetime, vessel fuel consumption calculation parameters, vessel statistics

- **Project lifecycle phases to consider**: Installation, Maintenance, Decommissioning
- **Phase requirements:** Installation, maintenance, and decommissioning preferences. Port selection preferences.
- **Operation methods:** Operation methods to consider, namely, device load-out method, cable landfall method, etc.

7.8.3.2 Inputs from External modules

In order to run the Logistics and Marine Operations module, different inputs from external modules are required:

1. Device dimensions, mass, and technology type from Machine Characterisation module
2. Number of devices and farm layout from Energy Capture module
3. Hierarchy file and PTO design inputs from the Energy Transformation module
4. Hierarchy file and energy grid design inputs from the Energy Delivery module
5. Hierarchy file and station keeping design inputs (moorings, foundations) from the Station Keeping module

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

7.8.3.3 Catalogue inputs

Apart from external inputs and User inputs, the Logistics and Marine Operations module uses databases of vessels, port terminals and equipment, as well as operations and activities data stored in a catalogue. These parameters may be changed by directly modifying the catalogue.

TABLE 7.44: CATALOGUES USED BY LMO

Operation methods	Data origin	Units
Port terminals	Catalogue	-
Vessel: Vessel combinations	Catalogue	-
Vessel: Vessel clusters	Catalogue	-
Equipment: Cable burial	Catalogue	-
Equipment: Piling	Catalogue	-
Equipment: ROVs	Catalogue	-
Equipment: Divers	Catalogue	-
Operations and activities (Installation, Maintenance, Decommissioning)	Catalogue	-

7.8.4 LMO Tutorials

7.8.4.1 Creating a new Logistics and Marine Operations study in standalone mode

Once logged into the server, the next step is to create a new study within the Logistics and Marine Operations 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. 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.*]

7.8.4.2 Using LOGISTICS AND MARINE OPERATIONS at low complexity in standalone mode

At low complexity (CPX1), the LMO module was developed to provide simplified logistic designs, requiring minimum inputs from the User and other design modules while minimizing computation times. The LMO GUI is divided into four stages: i) Project, ii) Operations, iii) Calculations, and iv) Results. In the first page, "Project", inputs are grouped into four input categories: i) Project inputs, which includes fundamental project parameters and device characteristics, ii) Other module inputs, which groups all the inputs related to farm subsystems from other modules run upstream and that are required to run LMO, iii) Site inputs, which consists of the input file from Site Characterisation related to the lease area coordinates, bathymetry and environmental timeseries, and iv) "Project lifecycle phases", where the user is able to select which phases to analyse (i.e. installation, maintenance, and/or decommissioning).

1) If required, create a new complexity level 1 study, as described in tutorial 1 (7.8.4.1).
2) From the list of studies, click 'Open' to start working on the complexity level 1 study
3) Click on the "Add" button in front of the "Project inputs" tab and:
   a) Select an Installation start date *[required[6]].*
   b) Select a Maintenance start date *[required[7]].*
   c) Specify whether device repair at the port is to be considered[8] *[optional]*
   d) Specify whether the device is fully submerged[9] *[optional]*
   e) Specify the maximum significant wave height (Hs)[10] *[required]*
   f) Specify the number of project years *[required]*

[6] Selecting an installation start month is only required in case the installation phase is to be analysed.
[7] Selecting a maintenance start month is only required in case the maintenance phase is to be analysed.
[8] In case this option is not selected, repair on site shall be considered.
[9] In case device is fully submerged, inspections to PTOs shall be carried out using ROVs or divers.
[10] Default: 2.5m

   g) Click "Save".
   h) If successful, the User will be redirected to the Project page. Otherwise, an error message will pop-up.
   i) To modify or visualise the introduced Project inputs, the "Update" button is now available. Otherwise, the User may just delete these project inputs by pressing "Delete".
4) Click on the "Add" button in front of the "Other module inputs" tab and:
   a) Confirm that you are on the MC module page. Click the upload button to introduce the MC input file. *[required]*
   b) On the module horizontal tab, select the EC module and upload the EC module input file. *[required]*
   c) Repeat the previous steps for each module. In the end, press the "Create" button *[required]*
   d) A confirmation pop-up message will appear. Press confirm *[required]*
   e) If successful, the User will be redirected to the Project page. Otherwise, an error message will pop-up.
5) Click on the "Add" button in front of the "Site inputs" tab and:
   a) Click on the upload button to introduce the Site data, as produced by the Site Characterisation module. *[required]*
   b) Press the "Create" button. *[required]*
   c) A loading sign will appear on top of the create button. If successful, the User will be redirected to the Project page. Otherwise, an error message will pop-up.
6) Specify which project lifecycle phases should be analysed in the current test.
   a) Press installation for simulating the installation phase
   b) Press maintenance for simulating the maintenance phase
   c) Press decommissioning for simulating the decommissioning phase[11]
7) Press the "Save and Lock". A loading sign will appear on top of the "Save and Lock" button. Otherwise, an error message will pop-up.
8) Once loading has been completed, the input tabs will be locked, not allowing for further changes. In case the inputs are to be changed, press the "Unlock" button. This will erase inputs that may have been introduced downstream in the next pages (Operations or Calculations). Then, to advance again, Step 7 must be repeated.
9) Once loading has been completed, the "Next" button will be unlocked. Press it to advance to the next page. *[required]*
10) The lifecycle phases selected on the "Project" page are now displayed. If all three phases were selected, then:
   a) Press the "Generate" button in front of the "Generate Installation operations". A loading sign will appear on top of the Generate button *[required]*
   b) Press the "Generate" button in front of the "Generate Maintenance operations". A loading sign will appear on top of the Generate button *[required]*
   c) Press the "Generate" button in front of the "Generate Decommissioning operations". A loading sign will appear on top of the Generate button. *[required]*

[11] The decommissioning phase can only be simulated if the installation phase also was selected.

   d) If successful, the "Generate" buttons will change to "Delete" buttons, which may be pressed to delete the generated operations. Otherwise, an error message will be shown.
   e) When every operation has been generated (every "Generate" button was replaced by a "Delete" button), press "Next".
11) The User will be redirected to the Calculations page.
   a) Press "Compute installation results" and wait. If successful, a confirmation message with the computation time will be presented, and the "Compute installation results" button will be replaced by a red "Delete installation results" button. Otherwise, an error message will be presented. *[required]*
   b) Press "Compute maintenance results" and wait. If successful, a confirmation message with the computation time will be presented and the "Compute maintenance results" button will be replaced by a red "Delete maintenance results" button. Otherwise, an error message will be presented. *[required]*
   c) Press "Compute decommissioning results" and wait. If successful, a confirmation message with the computation time will be presented and the "Compute decommissioning results" button will be replaced by a red "Delete decommissioning results" button. Otherwise, an error message will be presented. *[required]*
   d) Finally, press "View results"
12) The User will be redirected to the results page.
   a) Press to view the Installation Solution. This will redirect to the installation results page.
   b) Press to view the Maintenance Solution. This will redirect to the Maintenance results page.
   c) Press to view the Decommissioning Solution. This will redirect to the instal Decommissioning results page.

7.8.4.3 Using LOGISTICS AND MARINE OPERATIONS at medium/high complexity in standalone mode

In the case of higher data availability, the Logistics and Marine Operations 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 four input categories: i) Project inputs, which includes fundamental project parameters and device characteristics, ii) Other module inputs, which groups all the inputs related to farm subsystems from other modules run upstream and that are required to run LMO, iii) Site inputs, which consists of the input file from Site Characterisation related to the lease area coordinates, bathymetry and environmental timeseries, and iv) "Project lifecycle phases", where the user is able to select which phases to analyse (i.e. installation, maintenance, and/or decommissioning).

1) If required, create a new complexity level 3 study, as described in tutorial 1.
2) From the list of studies, click 'Open' to start working on the complexity level 3 study
3) Click on the "Add" button in front of the "Project inputs" tab and:
   a) Select an Installation start day *[required[12]]*.

[12] Selecting an installation start date is only required in case the installation phase is to be analysed.

b) Select a Maintenance start day *[required[13]]*.
c) Specify whether device repair at the port is to be considered[14] *[optional]*
d) Specify whether the device is fully submerged[15] *[optional]*
e) In case the device may be towed to the site, and the towing draft is significantly different from the device draft in resting conditions, then the towing draft may be specified:
    i) Press the consider checkbox *[optional]*
    ii) Specify the device towing draft in meters. *[optional]*
f) Specify the number of project years *[required]*
g) Specify the Safety factor for vessel selection. *[optional]*
h) Specify the vessel Fuel price to calculate fuel costs. *[optional]*
i) Specify Specific fuel oil consumption. *[optional]*
j) Specify the Average vessel load factor. *[optional]*
k) Press the statistics tab
    i) To modify the weather window statistic parameter, select the dropdown table. For this tutorial, leave it as Median (P50).
    ii) To modify the vessel statistics parameter, select the dropdown table. For this tutorial, leave it as Median (P50).
l) Click "Create".
m) If successful, the User will be redirected to the Project page. Otherwise, an error message will pop-up.
n) To modify or visualise the introduced Project inputs, the "Update" button is now available. Otherwise, the User may just delete these project inputs by pressing "Delete".

4) Click on the "Add" button in front of the "Other module inputs" tab and:
    a) Confirm that you are in the MC module page. Click the upload button to introduce the correct MC input file. *[required]*
    b) On the module horizontal tab, select the EC module, and upload the correct EC module input file. *[required]*
    c) Repeat the previous steps for each module. In the end, press the "Create" button *[required]*
    d) A confirmation pop-up message will appear. Press confirm *[required]*
    e) If successful, the User will be redirected to the Project page. Otherwise, an error message will pop-up.
5) Click on the "Add" button in front of the "Site inputs" tab and:
    a) Click on the upload button to introduce the Site data, as produced by the Site Characterisation module. *[required]*
    b) Press the "Create" button. *[required]*
    c) A loading sign will appear on top of the create button. If successful, the User will be redirected to the Project page. Otherwise, an error message will pop-up.
6) Specify which project lifecycle phases should be analysed in the current test.
    a) Press installation for simulating the installation phase

[13] Selecting a maintenance start date is only required in case the maintenance phase is to be analysed.
[14] In case this option is not selected, repair on site shall be considered.
[15] In case device is fully submerged, inspections to PTOs shall be carried out using ROVs or divers.

   b) Press maintenance for simulating the maintenance phase
   c) Press decommissioning for simulating the decommissioning phase[16]
7) Press the "Save and Lock". A loading sign will appear on top of the "Save and Lock" button. Otherwise, an error message will pop-up.
8) Once loading has been completed, the input tabs will be locked, not allowing for further changes. In case the inputs are to be changed, press the "Unlock" button. This will erase inputs that may have been introduced downstream in the next pages (Operations or Calculations). Then, to advance again, Step 7 must be repeated.
9) Once loading has been completed, the "Next" button will be unlocked. Press it to advance to the next page. *[required]*
10) The lifecycle phases selected on the "Project" page are now displayed. If all three phases were selected, then:
   a) Press the "Generate" button in front of the "Generate Installation operations". A loading sign will appear on top of the Generate button *[required]*
   b) Press the "Generate" button in front of the "Generate Maintenance operations". A loading sign will appear on top of the Generate button *[required]*
   c) Press the "Generate" button in front of the "Generate Decommissioning operations". A loading sign will appear on top of the Generate button. *[required]*
   d) If successful, the "Generate" buttons will change to "Delete" buttons, which may be pressed to delete the generated operations. Otherwise, an error message will be shown.
   e) When every operation has been generated (every "Generate" button was replaced by a "Delete" button), press "Next". The operation methods button will also be unlocked.
   f) In order to specify the optional phase requirements, press the "View" button. The User will be redirected to the Phase requirements page *[optional]*
      i) For each tab of the previously selected lifecycle phases to be considered (Installation, Maintenance, Decommissioning):
         (1) Specify whether ROVs or Divers should be considered to support subsea operations *[optional]*
         (2) Specify discarding criteria for the port selection process:
            (a) To discard ports that were not identified in the terminal catalogue has to have previous experience in MRE projects, select the respective checkbox *[optional]*
            (b) To discard ports with insufficient terminal area to accommodate the largest component, select the respective checkbox *[optional]*
            (c) To discard ports with insufficient quay loadbearing capacity, select the respective checkbox *[optional]*
            (d) To discard ports with insufficient crane capacity to lift the heaviest component[17] (in case lift loadouts are required), select the respective checkbox *[optional]*
            (e) To discard ports too far away, specify a radius centre on the site location, outside which the ports will be disregarded[18] *[optional]*

[16] The decommissioning phase can only be simulated if the installation phase also was selected.
[17] Bear in mind that onshore cranes may be externally hired so this may not be a strict port terminal requirement.
[18] Specifying port radius and reducing the total number of ports to be analysed will speed up calculations

(3) Repeat the same process for the maintenance and decommissioning lifecycle phases.

ii) In the end, press the button "Submit all". If successful, the User will be redirected to the Operations page. Otherwise, an error message will pop-up.

g) In order to specify the operation methods, press the "View" button. The User will be redirected to the Operation Methods page *[required]*

i) In the Devices tab:

(1) Specify the load-out method and the transportation method from the respective dropdown menus.

ii) In the Foundations tab, in case of Foundations exist in the project:

(1) Specify the foundation load-out and transportation methods from the respective dropdown menus.

(2) Specify the piling method for installing piles (if piles are to be installed)

iii) In the "Anchors and Moorings" tab, in case Moorings and anchors exist in the project:

(1) Specify the Anchor and Moorings load-out method from the dropdown menus.

iv) In the Collection Points tab, in case of Collection Points exist and require an individual operation in the project:

(1) Specify the collection point load-out and transportation methods from the respective dropdown menus.

v) In the Cables tab:

(1) Specify the cables burial-method and landfall method, which will affect the installation operations from the respective dropdown menus.

vi) In the end, press the button "Submit all". If successful, the User will be redirected to the Operations page. Otherwise, an error message will pop-up. *[required]*

11) The User will be redirected to the Calculations page.

a) Press "Compute installation results" and wait. If successful, a confirmation message with the computation time will be presented, and the "Compute installation results" button will be replaced by a red "Delete installation results" button. Otherwise, an error message will be presented. *[required]*

b) Press "Compute maintenance results" and wait. If successful, a confirmation message with the computation time will be presented, and the "Compute maintenance results" button will be replaced by a red "Delete maintenance results" button. Otherwise, an error message will be presented. *[required]*

c) Press "Compute decommissioning results" and wait. If successful, a confirmation message with the computation time will be presented, and the "Compute decommissioning results" button will be replaced by a red "Delete decommissioning results" button. Otherwise, an error message will be presented. *[required]*

d) Finally, press "View results"

12) The User will be redirected to the results page.

a) Press to view the Installation Solution. This will redirect to the installation results page.

b) Press to view the Maintenance Solution. This will redirect to the Maintenance results page.

c) Press to view the Decommissioning Solution. This will redirect to the instal Decommissioning results page.

7.8.5 LMO How-to Guides

7.8.5.1 How to prepare data for using the Logistics and Marine Operations module

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

7.8.5.1.1 Format the Machine Characterisation input file

The Machine Characterisation input file compiles information related to the device, stored in a json format. The file describes whether the device is floating (TRUE) or bottom-fixed (FALSE), specifies the device structural costs (*machine_costs*), as well as the device dimensions (in m) and mass (in kg), crucial parameters to specify areas, and load requirements. An example input file for the RM3 (VS2_VCx) test case is provided in Table 7.45.

TABLE 7.45: MACHINE CHARACTERISATION INPUT FILE

{ "general": {
"**floating**": true,
"**machine_cost**": 2939052.37 },
"dimensions": {
"**draft**": 35,
"**height**": 42,
"**width": 30,**
"**length**": 30,
"**mass**": 680000 } }

7.8.5.1.2 Format the Energy Capture input file

The Energy Capture input file compiles information related to the farm, stored in a json format. The file includes data such as the number of devices, list of device IDs, and coordinates (latitude and longitude). An example input file for a farm of 10 devices (VS2_VC5) is provided in Table 7.46.

TABLE 7.46: ENERGY CAPTURE INPUT FILE

{ "layout": {
"**deviceID**": [1,2,3,4,5,6,7,8,9,10],
"**latitude**": [0,10,20,30,40,50,60,70,80,90,100],
"**longitude**": [0,10,20,30,40,50,60,70,80,90,100] },
"**number_devices**": 10 }

7.8.5.1.3 Format the Energy Transformation input files

The input file from the Energy Transformation module is significantly more complex than the two previous ones. Firstly, the input file includes the ET system hierarchy, described in the D6.3 RAMS alpha version [18], which expresses the relationships between components and subsystems of the Energy Transformation system. Secondly, the ET input file includes the costs and masses of the PTO components for each device.

The hierarchy trees can be partially understood as the inverse of a failure tree, built using Boolean logic to evaluate whether components are working (1) or not (0). This allows the quantification of the impacts of component critical failure on the system and identifies which critical component failures to generate critical failures at the system level for each device.

In the hierarchy, all components are listed. Each component/subsystem has an identifiable *design id* and a node name *(name_of_node).* Indivisible components are referred to as "Level 0" and have no "Children". A bottom-up approach from child to parent is adopted for defining category levels, from Level 0 all the way up to the top node: ET1 (installed in device OEC1). Each device may have more than one PTO, which may be operating simultaneously (this is the case of RM1). Each PTO may be decomposed into three different parts: the mechanical transformation system ("MechT" – e.g. air turbine), the electrical transformation system ("ElecT" – e.g. generator), and the grid conditioning system ("GridC", e.g. back to back power converter). Components and subsystems may have specified failure rates. Hierarchical relationships are expressed by the components listed as children, as well as the logic gate, which defines the type of relationship (the AND gate means that all children must be working for the parent system being operational, OR gate means that at least one child must be operational).

TABLE 7.47: ENERGY TRANSFORMATION INPUT FILE FOR ONE RM1 DEVICE.


```
{ "array": {
 "Hierarchy": {
        "value": {
               "category": [
                      "Level 3",
                      "Level 2",
                      "Level 1",
                      "Level 0",
                      "Level 0",
                      "Level 0",
                      "Level 1",
                      "Level 0",
                      "Level 0",
                      "Level 0"
               ],
               "child": [
                     ["ET1"],
```

```
                    ["ET1_PTO_0_0", "ET1_PTO_1_0"],
                    ["ET1_PTO_0_0_MechT","ET1_PTO_0_0_ElectT",
"ET1_PTO_0_0_GridC"],
                    "NA",
                    "NA",
                    "NA",
                    ["ET1_PTO_1_0_MechT",              "ET1_PTO_1_0_ElectT",
"ET1_PTO_1_0_GridC"],
                    "NA",
                    "NA",
                    "NA" ],
              "design_id": [
               "Array_01",
               "Array_01",
               "Array_01",
               "Array_01",
               "Array_01",
               "Array_01",
               "Array_01",
               "Array_01",
               "Array_01",
               "Array_01"
              ],
              "failure_rate_replacement": [
               "NA",
               "NA",
               "NA",
               0.008785833,
               0.00136,
               0.004547059,
               "NA",
               0.008785833,
               0.00136,
               0.004547059
              ],
              "failure_rate_repair": [
               "NA",
               "NA",
               "NA",
               "NA",
               "NA",
               "NA",
```

```
 "NA",
 "NA",
 "NA",
 "NA"
],
"gate_type": [
        "AND",
        "OR",
        "AND",
        "AND",
        "AND",
        "AND",
        "AND",
        "AND",
        "AND",
        "AND"
],
"name_of_node": [
        "Array_01",
        "ET1",
        "ET1_PTO_0_0",
        "ET1_PTO_0_0_MechT",
        "ET1_PTO_0_0_ElectT",
        "ET1_PTO_0_0_GridC",
        "ET1_PTO_1_0",
        "ET1_PTO_1_0_MechT",
        "ET1_PTO_1_0_ElectT",
        "ET1_PTO_1_0_GridC"
],
"node_subtype": [
        "NA",
        "NA",
        "NA",
        "NA",
        "NA",
        "NA",
        "NA",
        "NA",
        "NA",
        "NA"
],
"node_type": [
```

```
                    "System",
                    "Device",
                    "PTO",
                    "Component",
                    "Component",
                    "Component",
                    "PTO",
                    "Component",
                    "Component",
                    "Component"
                ],
                "parent": [
                    "NA",
                    ["Array_01"],
                    ["ET1"],
                    ["ET1_PTO_0_0"],
                    ["ET1_PTO_0_0"],
                    ["ET1_PTO_0_0"],
                    ["ET1"],
                    ["ET1_PTO_1_0"],
                    ["ET1_PTO_1_0"],
                    ["ET1_PTO_1_0"]
                ],
                "system": [
                    "ET",
                    "ET",
                    "ET",
                    "ET",
                    "ET",
                    "ET",
                    "ET",
                    "ET",
                    "ET",
                    "ET"
                ]
            }
    }
},
"devices": [
    {
        "Dev_PTO_cost": {
            "value": 1908099
```

```
        },
        "Dev_PTO_mass": {
            "value": 109000
        },
        "Dev_rated_power": {
            "value": 300.0
        },
        "id": {
            "value": "1"
        },
        "ptos": [
            {
            "Elect_cost": {
                "value": 254725
            },
            "Elect_mass": {
                "value": 109000
            },
            "Grid_cost": {
                "value": 522587
            },
            "Grid_mass": {
                "value": 109000
            },
            "Mech_cost": {
                "value": 1130786.938
            },
            "Mech_mass": {
                "value": 109000
            },
            "id": {
                "value": "PTO_0_0"
            }
            },
            {
                "Elect_cost": {
                    "value": 254725
                },
                "Elect_mass": {
                    "value": 109000
                },
                "Grid_cost": {
```

```
                        "value": 522587
                    },
                    "Grid_mass": {
                        "value": 109000
                    },
                    "Mech_cost": {
                        "value": 1130786.938
                    },
                    "Mech_mass": {
                        "value": 109000

                    },
                    "id": {
                        "value": "PTO_1_0"
                    }
                }
            ]
  }
]
}
```

7.8.5.1.4 Format the Energy Delivery inputs

TABLE 7.48: ENERGY DELIVERY INPUT FILE FOR ONE RM1 DEVICE


```
{
  "cable_dict": [
    {
      "burial_depth": [
        0.5,
        0.5,
        0.5,
        0.5,
        ...
      ],
      "cable_mattress": [
        false,
        false,
        false,
        false,
        ...
      ],
      "cable_x": [
        398675.0,
        398625.0,
        398575.0,
        398525.0,
        ...
      ],
      "cable_y": [
        4518475.0,
        4518475.0,
        4518525.0,
        4518575.0,
        ...
      ],
      "cost": 5344755.072177423,
      "layer_1_start": [
        -2.84319,
        -3.43957,
        -4.3625898,
        -5.28549,
        ...
      ],
      "layer_1_type": [
        "loose sand",
        "loose sand",
        "loose sand",
```

```
        "loose sand",
        ...
      ],
      "length": 6680.943840221778,
      "marker": 0,
      "split_pipe": [
        false,
        false,
        false,
        ...
      ],
      "type_": "export",
    }
  ],
  "cable_installation": "Ploughing",
  "collection_point_dict": [
   {
    "cost": 1410128,
    "input_connectors": null,
    "location": null,
    "marker": "CP1",
    "output_connectors": null,
    "type_": "passive hub"
    }
  ],
  "connectors_dict": [
    {
      "cost": 150000.0,
      "db_key": 125,
      "marker": 1,
      "type_": "wet-mate",
      "utm_x": 393295.0,
      "utm_y": 4521615.0
    },
    {
      "cost": 150000.0,
      "db_key": 125,
      "marker": 3,
      "type_": "wet-mate",
      "utm_x": 393285.0,
      "utm_y": 4521615.0
    }
  ],

  "hierarchy_new": {
    "category": [
```

```
    "Level 3",
    "Level 2",
    "Level 1",
    "Level 0",
    "Level 0",
    "Level 0",
    "Level 0"
  ],
  "child": [
    [
      "ED1"
    ],
    [
      "Route1_1"
    ],
    [
      "3",
      "2",
      "1",
      "0"
    ],
    "NA",
    "NA",
    "NA",
    "NA"
  ],
  "design_id": [
    "NA",
    "NA",
    "NA",
    "2",
    "0",
    "3",
    "1"
  ],
  "failure_rate_repair": [
    "NA",
    "NA",
    "NA",
    0.009079056765100056,
    1.0007786634898617,
    0.047500574399999995,
    0.047500574399999995
  ],
  "failure_rate_replacement": [
    "NA",
```

```
        "NA",
        "NA",
        0.00907905676510056,
        1.0007786634898617,
        0.047500574399999995,
        0.047500574399999995
    ],
    "gate_type": [
        "OR",
        "OR",
        "AND",
        "NA",
        "NA",
        "NA",
        "NA"
    ],
    "name_of_node": [
        "ED Subsystem",
        "ED1",
        "Route1_1",
        "2",
        "0",
        "3",
        "1"
    ],
    "node_subtype": [
        "NA",
        "NA",
        "NA",
        " umbilical",
        " export",
        " wet-mate",
        " wet-mate"
    ],
    "node_type": [
        "System",
        "System",
        "Energy route",
        "Component",
        "Component",
        "Component",
        "Component"
    ],
    "parent": [
        "NA",
        "NA",
```

```
      [
        "ED1"
      ],
      [
        "Route1_1"
      ],
      [
        "Route1_1"
      ],
      [
        "Route1_1"
      ],
      [
        "Route1_1"
      ]
    ],
    "system": [
      "ED",
      "ED",
      "ED",
      "ED",
      "ED",
      "ED",
      "ED"
    ]
  },
  "umbilical_dict": [
    {
      "cost": 48487.57918823232,
      "device": "Device001",
      "length": 60.60947398529039,
      "marker": 2,
      "seabed_connection_point": [
        393295.0,
        4521615.0,
        -51.7464981
       ]

    }
  ]
}
```

7.8.5.1.5 Format the Station Keeping input files

TABLE 7.49: STATION KEEPING INPUT FILE FOR ONE RM1 DEVICE


```
{
 "hierarchy": {
   "system": [
     "SK",
     "SK",
     "SK",
     "SK",
     "SK",
     "SK",
     "SK",
     "SK",
     "SK",
     "SK",
     "SK"
   ],
   "name_of_node": [
     "SK1_x",
     "SK1_x_ml_0_seg_0",
     "SK1_x_ml_0_anchor_n_2_0",
     "SK1_x_ml_0",
     "SK1_x_ml_1_seg_0",
     "SK1_x_ml_1_anchor_n_2_0",
     "SK1_x_ml_1",
     "SK1_x_ml_2_seg_0",
     "SK1_x_ml_2_anchor_n_2_0",
     "SK1_x_ml_2",
     "SK1"
   ],
   "design_id": [
     "NA",
     "SK1_x_ml_0_seg_0",
     "SK1_x_ml_0_anchor_n_2_0",
     "NA",
     "SK1_x_ml_1_seg_0",
     "SK1_x_ml_1_anchor_n_2_0",
     "NA",
     "SK1_x_ml_2_seg_0",
     "SK1_x_ml_2_anchor_n_2_0",
     "NA",
     "NA"
   ],
```

```
    "node_type":[
      "System",
      "Component",
      "Component",
      "System",
      "Component",
      "Component",
      "System",
      "Component",
      "Component",
      "System",
      "System"
    ],
    "node_subtype":[
      "stationkeeping",
      "line_segment",
      "anchor",
      "mooring_line",
      "line_segment",
      "anchor",
      "mooring_line",
      "line_segment",
      "anchor",
      "mooring_line",
      "stationkeeping"
    ],
    "category":[
      "Level 2",
      "Level 0",
      "Level 0",
      "Level 1",
      "Level 0",
      "Level 0",
      "Level 1",
      "Level 0",
      "Level 0",
      "Level 1",
      "Level 3"
    ],
    "parent":[
      "NA",
      "SK1_x_ml_0",
      "SK1_x_ml_0",
      "SK1_x",
      "SK1_x_ml_1",
      "SK1_x_ml_1",
```

```
      "SK1_x",
      "SK1_x_ml_2",
      "SK1_x_ml_2",
      "SK1_x",
      "NA"
    ],
    "child": [
      [
        "SK1_x_ml_0",
        "SK1_x_ml_1",
        "SK1_x_ml_2"
      ],
      [
        "NA"
      ],
      [
        "NA"
      ],
      [
        "SK1_x_ml_0_seg_0",
        "SK1_x_ml_0_anchor_n_2_0"
      ],
      [
        "NA"
      ],
      [
        "NA"
      ],
      [
        "SK1_x_ml_1_seg_0",
        "SK1_x_ml_1_anchor_n_2_0"
      ],
      [
        "NA"
      ],
      [
        "NA"
      ],
      [
        "SK1_x_ml_2_seg_0",
        "SK1_x_ml_2_anchor_n_2_0"
      ],
      [
        "SK1_x"
      ]
    ],
```

```
    "gate_type":[
      "AND",
      "NA",
      "NA",
      "AND",
      "NA",
      "NA",
      "AND",
      "NA",
      "NA",
      "AND",
      "AND"
    ],
    "failure_rate_repair": [
      "NA",
      0.0000000001,
      0.0000000001,
      "NA",
      0.0000000001,
      0.0000000001,
      "NA",
      0.0000000001,
      0.0000000001,
      "NA",
      "NA"
    ],
    "failure_rate_replacement":[
      "NA",
      2.4352799999999997,
      0.0000000001,
      "NA",
      2.4352799999999997,
      0.0000000001,
      "NA",
      2.4352799999999997,
      0.0000000001,
      "NA",
      "NA"
    ],
    "hierarchy_data": {
      "anchor_list": [
        {
          "design_id":"SK1_x_ml_0_anchor_n_2_0",
          "type":"drag_anchor",
          "height":3.2907521354288622,
          "width": 5.898160564005535,
```

```
"length": 5.471773895058202,
"mass": 9535.483174496047,
"upstream_id": [
  "SK1_x_ml_0"
],
"downstream_id": [
  "NA"
],
"coordinates": [
  350,
  0,
  -70
],
"cost": 47677.41587248023
},
{
"design_id": "SK1_x_ml_1_anchor_n_2_0",
"type": "drag_anchor",
"height": 3.2907521354288622,
"width": 5.898160564005535,
"length": 5.471773895058202,
"mass": 9535.483174496047,
"upstream_id": [
  "SK1_x_ml_1"
],
"downstream_id": [
  "NA"
],
"coordinates": [
  -175.0,
  303.108,
  -70.0
],
"cost": 47677.41587248023
},
{
"design_id": "SK1_x_ml_2_anchor_n_2_0",
"type": "drag_anchor",
"height": 3.2907521354288622,
"width": 5.898160564005535,
"length": 5.471773895058202,
"mass": 9535.483174496047,
"upstream_id": [
  "SK1_x_ml_2"
],
"downstream_id": [
```

```
            "NA"
          ],
          "coordinates": [
            -175.0,
            -303.108,
            -70.0
          ],
          "cost": 47677.41587248023
        }
      ],
      "foundation_list": [],
      "line_segment_list": [
        {
          "design_id": "SK1_x_ml_0_seg_0",
          "material": "nylon",
          "length": 340.7,
          "total_mass": 4703.105113119999,
          "diameter": 0.146,
          "upstream_id": [
            "NA"
          ],
          "downstream_id": [
            "NA"
          ],
          "cost": 17371.5679904
        },
        {
          "design_id": "SK1_x_ml_1_seg_0",
          "material": "nylon",
          "length": 340.7,
          "total_mass": 4703.105113119999,
          "diameter": 0.146,
          "upstream_id": [
            "NA"
          ],
          "downstream_id": [
            "NA"
          ],
          "cost": 17371.5679904
        },
        {
          "design_id": "SK1_x_ml_2_seg_0",
          "material": "nylon",
          "length": 340.7,
          "total_mass": 4703.105113119999,
          "diameter": 0.146,
```

```
            "upstream_id": [
              "NA"
            ],
            "downstream_id": [
              "NA"
            ],
            "cost": 17371.5679904
          }
        ]
      }
    }
  }
```

8. ANNEX II: SOFTWARE EVALUATION FORM – STANDALONE VERSIONS

8.1 SITE CHARACTERISATION (SC)

Tool – Module: Deployment Design Tool - Site Characterisation

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 per software Feature. A Feature is the 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

[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 MACHINE CHARACTERISATION (MC)

Tool – Module: Deployment Design Tool - Machine Characterisation

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 per software Feature. 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]

8.3 ENERGY CAPTURE (EC)

Tool – Module: Deployment Design Tool - Energy Capture

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 per software Feature. 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]

8.4 ENERGY TRANSFORMATION (ET)

Tool – Module: Deployment Design Tool - Energy Transformation

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 per software Feature. 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: Array/Device/PTO Outputs

[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]

8.5 ENERGY DELIVERY (ED)

Tool – Module: Deployment Design Tool - Energy Delivery

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 per software Feature. A Feature is a main functionality of the software that adds value to the user.

a. Feature Tested: Simplified design mode (complexity 1, VC1.1 & 1.2)

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

[Please add other key points and comments]

b. Feature Tested: Full design mode (complexity level 2 or 3, VC2.1-2.13)

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

Comments

[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]

8.6 STATIONKEEPING (SK)

Tool – Module: Deployment Design Tool - Stationkeeping

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 per software Feature. 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

[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]

8.7 LOGISTICS AND MARINE OPERATIONS (LMO)

Tool – Module: Deployment Design Tool - Logistics and Marine Operations

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 per software Feature. 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: Installation solution

[Please add other key points and comments]

Comments about Outputs: Maintenance solution

[Please add other key points and comments]

Comments about Outputs: Decommissioning solution

[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 SITE CHARACTERISATION (SC)

Scores

TABLE 9.1: USABILITY OF SC

ID	Statement	Resp. 1	Resp. 2	Resp. 3	Resp. 4	Resp. 5	Resp. 6	Resp. 7
1.1	The software is intuitive and easy to use in general	5	5	4	5	4	5	5
1.2	It is easy to create and delete a Study	5	5	5	5	4	5	5
1.3	It is easy to edit, save and export a Study	5	4	3	3	5	5	5
1.4	The process of inputting data is clear and efficient	4	4	3	5	4	5	5
1.5	Results are meaningful, easy to interpret and use	4	4	5	5	3	5	5
1.6	I could complete the process without errors	5	5	3	5	3	5	5
1.7	I am satisfied with the overall speed of computation	5	4	5	1	4	5	5
1.8	The software can be run from my computer without any issue	5	4	5	3	1	5	5
1.9	The training sessions and documentation are useful for learning how to use the software	5	5	4	5	4	5	5

TABLE 9.2: USER-FRIENDLINESS OF SC

ID	Statement	Resp. 1	Resp. 2	Resp. 3	Resp. 4	Resp. 5	Resp. 6	Resp. 7
2.1	The user interface is simple, easy to navigate and well-organised	5	4	4	5	4	5	5
2.2	The user interface looks professional	5	3	3	5	2	5	3
2.3	It responds promptly to user actions (inputs, selections, clicks, …)	5	4	5	3	5	5	5
2.4	It provides the user with enough help, indications and/or guidance throughout each process	4	2	3	5	2	5	5
2.5	The meaning of each data input/user selection is clear	4	3	5	5	3	5	5
2.6	The meaning of each data output is clear	4	4	5	4	3	5	5
2.7	Visualisation of results is clear and informative	4	4	5	5	4	5	5
2.8	The user can add further information to the Study through the interface	5	3	1	4	2	5	4

TABLE 9.3: PERFORMANCE AND ACCURACY OF SC

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

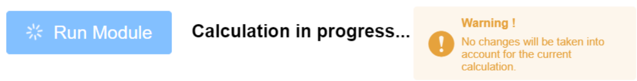
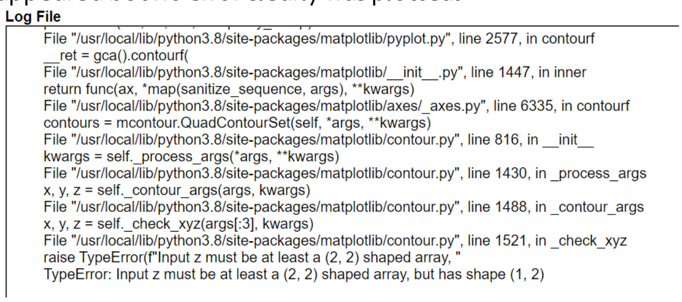
TABLE 9.4: VALUE OF SC

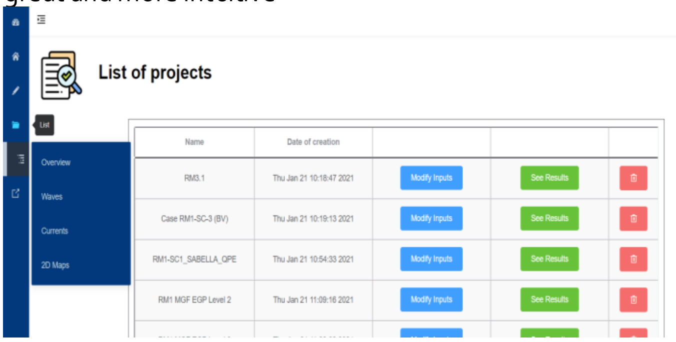
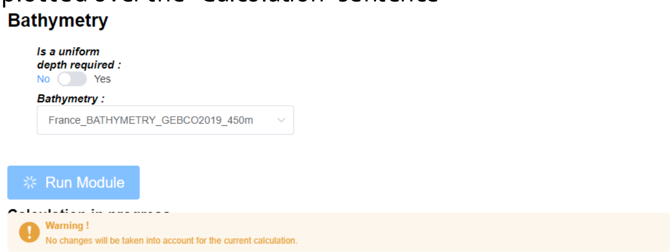
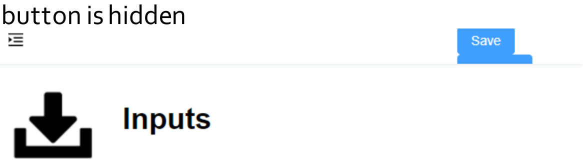
ID	Statement	Resp. 1	Resp. 2	Resp. 3	Resp. 4	Resp. 5	Resp. 6	Resp. 7
4.1	The software allows the user full control of the design process	5	2	-	3	3	5	5
4.2	It produces results that allow easy comparisons	5	2	5	4	4	5	5
4.3	It provides a large range of alternatives to create/assess technologies	4	3	-	4	3	5	5
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies	3	2	4	2	2	4	5
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality	4	3	3	4	4	5	5
4.6	I would recommend the use of this software	4	4	4	3	4	5	5

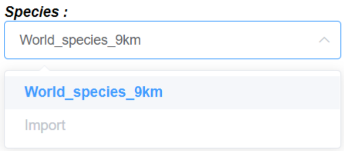
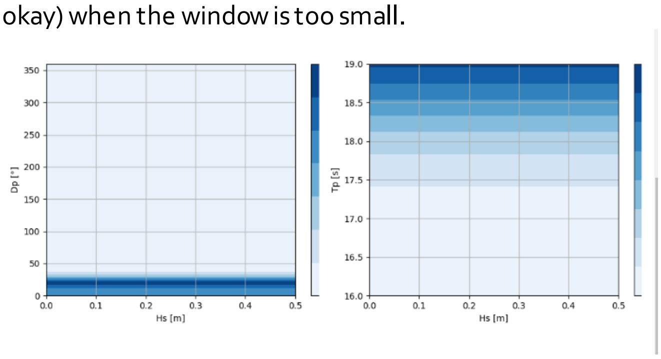
Comments

TABLE 9.5: COMMENTS FOR SC

ID	Feature	Subject	Comments
1	User-Friendliness	-	Perhaps include key to all abbreviations/acronyms, and/or direct links to a glossary or appropriate page of user manual for calculations reference? Transparency on calculation is critical to user confidence.
2	Performance and Accuracy	-	Only threw in a few deliberate errors/options, not a comprehensive test! Does software check consistency of input data sources? E.g. for a study using geographically mismatched data sources: 'E2RM1_lease_area' and 'RM1_corridor_WGS84' throws exceptions but continues trying to calculate rather than aborting.
3	Value	-	Logfile – working well and understandable as processing undertaken when no data errors present. Less clear when errors or exceptions such as data mismatches are present.
4	General remarks	-	'Export Results to PDF' not working for 2D Maps?
5	Usability	-	It wasn't possible to export the study as a pdf (the user gets the following message: 'This project was not run yet'), but maybe this functionality hasn't been implemented yet.
6	Performance and Accuracy	-	There was a lack of information of the databases utilised when running the module.
7	Performance and Accuracy	-	It was noticed that the user hasn't much freedom of changing the inputs, so the score was given according to the level of freedom encountered when running the cases.
8	Value	-	Adding comparisons between different geographical sites might be considered for future developments of the module.
9	Usability	-	The inputs for the complexity 3 heavily rely on uploaded files, and the capability of the user to create those files is questionable. At list the user should be directed to a page where those files are described.
10	Usability	-	The calculation at CPX1 took significantly longer time than CPX3. Why?
11	Usability	-	The 2D maps did not show in any of the case run, maybe adding an informative message, rather than "No 2D maps for this project", why?
12	User-Friendliness	-	The distribution of the items in the SCHome is questionable. Load Project does not work, redirect to the List page.
13	User-Friendliness	-	The project List can be improved with a search/filter area or at least adding an ordering button
14	User-Friendliness	-	The output pages items are not centered and depending on the window size the main are could be better arranged.
15	User-Friendliness	-	The possibility of adding further information to the Study through the interface seems not to be available
16	Performance and Accuracy	-	Changing the water depth from 50 to -10, did not throw any error and did not changed the results apart from the water depth variation.
17	Performance and Accuracy	-	The results are the same for all the level of complexity, I've tried.

ID	Feature	Subject	Comments
18	Value	-	Remaining time would be a nice to have feature, maybe a simple message the calculation might require 2-5mins or whatever the developer experience would be.
19	Value	-	The non-interactive plot is not optimal.
20	General remarks	-	Adding a copy project functionality for better comparison might be a nice feature and also the process of editing an existing project is not clear. For example, how to change the project title become clear only after the input are changed.
21	Usability	-	The time of the computation is very long.
22	User-Friendliness	-	It had problems with displaying the end of the process
23	Value	-	There are some problems with the communication of the remaining time to the end of the process
24	Usability	-	When no Complexity Level is provided, it is still possible to Run the Module  The computation is launched and cannot be stopped, and the study cannot be deleted.
25	Usability	-	With the RM1-SC4 scenario, we could have values for return periods for waves, but not for currents, which are necessary data to design turbines. Making this available to the user seems mandatory. The graphs plotted are nice, but the statistical values are not realistic for these tests, are they? (Waves graphs for scenario 3)
26	Usability	-	Scenario 4 bugged once (run indefinitely). A weird message appeared but no error clearly was plotted.  Log File File "/usr/local/lib/python3.8/site-packages/matplotlib/pyplot.py", line 2577, in contourf __ret = gca().contourf(File "/usr/local/lib/python3.8/site-packages/matplotlib/__init__.py", line 1447, in inner return func(ax, *map(sanitize_sequence, args), **kwargs) File "/usr/local/lib/python3.8/site-packages/matplotlib/axes/_axes.py", line 6335, in contourf contours = mcontour.QuadContourSet(self, *args, **kwargs) File "/usr/local/lib/python3.8/site-packages/matplotlib/contour.py", line 816, in __init__ kwargs = self._process_args(*args, **kwargs) File "/usr/local/lib/python3.8/site-packages/matplotlib/contour.py", line 1430, in _process_args x, y, z = self._contour_args(args, kwargs) File "/usr/local/lib/python3.8/site-packages/matplotlib/contour.py", line 1488, in _contour_args x, y, z = self._check_xyz(args[:3], kwargs) File "/usr/local/lib/python3.8/site-packages/matplotlib/contour.py", line 1521, in _check_xyz raise TypeError(f"Input z must be at least a (2, 2) shaped array, " TypeError: Input z must be at least a (2, 2) shaped array, but has shape (1, 2)
27	User-Friendliness	-	When you click on "export the results", if you don't save the data or quit the new tab, you can still access the working tab but can't click on anything (can't move the page, the mouth is not an arrow but a hand...). The user needs to realize by himself what the problem is and close the "exporting" window.

ID	Feature	Subject	Comments
28	User-Friendliness	-	I found disturbing to be able to access results for the last study being led, via the lefthand panel, in the same place as the "new study" button and the list of other studies at the same "high level" commands, and not being able to directly access the inputs (to check or modify it) via this high level panel. Maybe separating the current study from all the others high-level buttons, and having a kind of "subpanel" with inputs and results (like the one with overview, waves, currents, 2d maps, which would be at a third level) could be great and more intuitive 
29	User-Friendliness	-	When the internet window is not full screen, the "warning" is plotted over the "Calculation" sentence 
30	User-Friendliness	-	When the internet window is not full screen, the "save as" button is hidden 
31	User-Friendliness	-	Values for wind speeds at the area considered are given, but guidance on why these default values are used would be appreciated
32	User-Friendliness	-	"Help" buttons could be added to give more information on the input to give (what is expected, what formats are accepted or not etc)
33	User-Friendliness	-	Explaining what is intended by low, medium, high levels of energy when using a low complexity levels (range of values ?)
34	User-Friendliness	-	Warning the user that he won't be able to see 2d maps in results because the inputs are too loose to allow it would be great

<table>
<tr><th>ID</th><th>Feature</th><th>Subject</th><th>Comments</th></tr>
<tr><td>35</td><td>User-Friendliness</td><td>-</td><td>The import option is not possible, with a red crossed circle indicating that this option is not allowed: removing it if not usable could be great
</td></tr>
<tr><td>36</td><td>User-Friendliness</td><td>-</td><td>In the Waves and in the Current pages, the variables displayed in the array should be clearly stated to the user, because Cge, Spr may not be things usually used by all the users</td></tr>
<tr><td>37</td><td>User-Friendliness</td><td>-</td><td>The units don't appear in outputs Currents and Waves section (neither on internet nor on the exported PDF).
<table>
<tr><th>Variable name</th><th>Minimum</th><th>Maximum</th><th>Mean</th><th>Median</th><th>STD</th></tr>
<tr><td>Hs</td><td>0</td><td>5.55</td><td>1.07</td><td>0.93</td><td>0.6</td></tr>
<tr><td>Tp</td><td>2.42</td><td>21.28</td><td>10.67</td><td>10.64</td><td>2.99</td></tr>
<tr><td>Cge</td><td>0</td><td>162.7</td><td>6.4</td><td>3.2</td><td>9.19</td></tr>
<tr><td>Gamma</td><td>1</td><td>5</td><td>1.08</td><td>1</td><td>0.44</td></tr>
<tr><td>Spr</td><td>2.4</td><td>80.4</td><td>42.85</td><td>40.5</td><td>14.25</td></tr>
</table></td></tr>
<tr><td>38</td><td>User-Friendliness</td><td>-</td><td>Mag and Theta should be further defined, and could even be presented in a compass-like plot with North, East… shown</td></tr>
<tr><td>39</td><td>User-Friendliness</td><td>-</td><td>When only one point is selected for the graphs, the choice made should be specified (for instance, the height chosen for currents, or if it's an average over height etc). Maybe the author is supposed to know it because the input data is already averaged over height, but it could be specified anyway in the exported file (or at least the input chosen).</td></tr>
<tr><td>40</td><td>User-Friendliness</td><td>-</td><td>EJDP in the PDF is not really clear (Extreme Joint Distribution P… ?)</td></tr>
<tr><td>41</td><td>User-Friendliness</td><td>-</td><td>A reference, the site name, or something indicating the site which is studied in the Overview page could be great</td></tr>
<tr><td>42</td><td>User-Friendliness</td><td>-</td><td>I suggest to allow the user to export results under an Excel file in addition to the PDF format, particularly for the MAG-THETA or Hs-Tp/ Hs-Dp plots (with discretization steps that would be defined by the user), because values are hard/impossible to extract, though the plots are beautiful</td></tr>
<tr><td>43</td><td>User-Friendliness</td><td>-</td><td>In the outputs Waves section, the title/values in the colorbar does not display (but in the exported PDF, this feature is okay) when the window is too small.
</td></tr>
</table>

ID	Feature	Subject	Comments
44	User-Friendliness	-	More information about the inputs should appear on the exported PDF (the names of each input "bathy_XXX", "seabed_XXX"…, maybe also the author name, date of creation etc).
45	User-Friendliness	-	We didn't see any option for the user to add new features of the site.
46	Performance and Accuracy	-	We had no access to input data, so it is hard to tell if calculations seem correct
47	Performance and Accuracy	-	I suggest you remove the latitude and longitude for complexity level 1, as the position for a site which does not really exist is meaningless
48	Value	-	I found surprising that the user is not allowed to provide his own site
49	Value	-	When this will be possible (if it is supposed to be), it will be important to clearly explain to the user the type of data, the format to use, and possibly prefer an Excel file to upload to a json file, because many people are not used to it.
50	Value	-	The user is not informed on the remaining time which misleads him when the calculation is infinite because of a bug
51	Value	-	The graphs and arrays are what are expected for a new site for the first studies. And the 2D maps are a nice Figure to add in a report.
52	Performance and Accuracy	-	The first attempt of calculation for RM3-SC3 case was time demanding. I had to stop the calculation and run it other time. In this second time, the module execution was OK and the run time was very similar to the estimated one and reported in the Technical note of the Verification tests Site Characterisation module. I used the standalone version in both cases.
53	General remarks	-	The SC module has been tested with the case RM3 (SC1, SC2, SC3, and SC4).
54	General remarks	-	It is not clear why for RM3-SC4 the Wave Hs does not change considering a return period from 5 to 50 years.
55	General remarks	-	The statistics values of the flux variable related to the Currents output, present unrealistic values, when RM3-SC4 has been run.
56	Usability	-	Everything went well when running the case.
57	Performance and Accuracy	-	The software is great: the only little point which can be improved is to make an interface more professional, otherwise everything is great and answers to what we want to do.

9.2 MACHINE CHARACTERISATION (MC)

Scores

TABLE 9.6: USABILITY OF MC

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

TABLE 9.7: USER-FRIENDLINESS OF MC

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

TABLE 9.8: PERFORMANCE AND ACCURACY OF MC

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

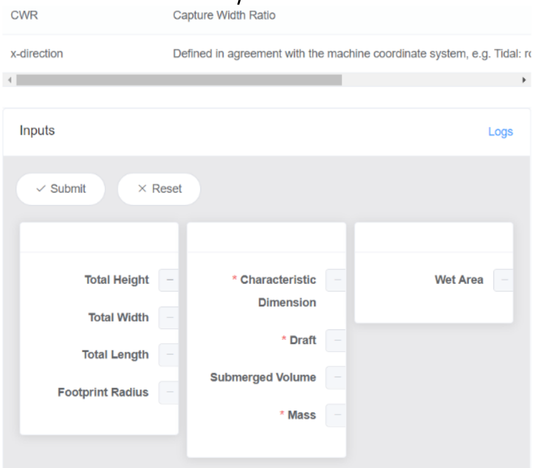
Fully aggregated results have been analysed without differentiating scores between VSs and functionalities. In all cases the average value per statement has been considered.

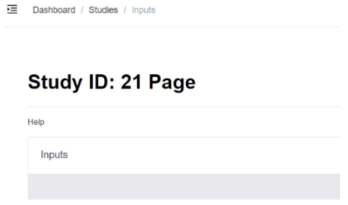
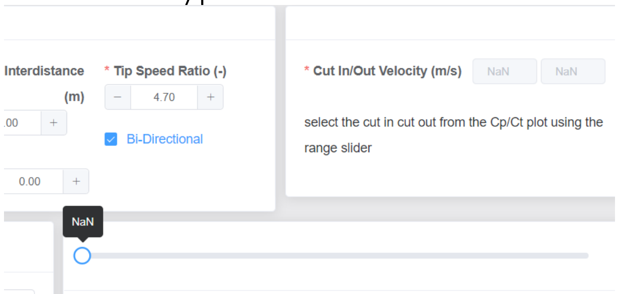
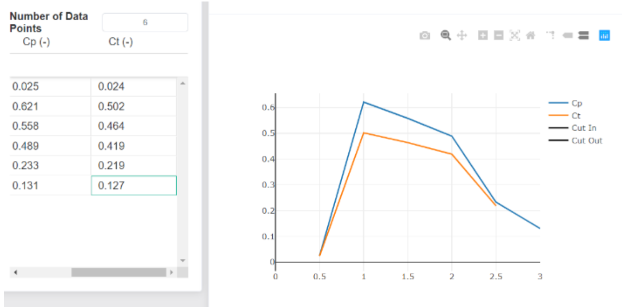
TABLE 9.9: VALUE OF MC

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

Comments

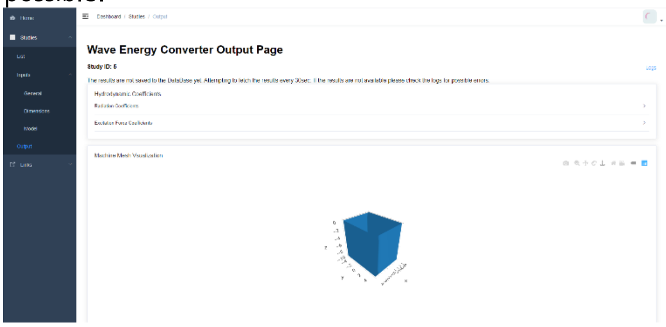
TABLE 9.10: COMMENTS FOR MC

ID	Feature	Subject	Comments
1	Usability	-	Please note we couldn't rate all statements – e.g. there is no calculation undertaken in MC module for a TEC?
2	Usability	-	The study title is not properly displayed when in the study pages – "Study ID: 4 Page" etc. rather than actual title.
3	Usability	-	Need better input box labels including units, and perhaps info. pop-ups or link to a reference document to what each term precisely means. E.g. 'Heading Angle Span', 'Constant Power Factor', 'Characteristic Dimension', various 'Areas' etc.
4	Usability	-	It is probable that the process could be complete without errors, but no real way of checking as no calculation?
5	User-Friendliness	-	Maybe including direct links to a glossary or appropriate page of user manual.
6	User-Friendliness	-	No outputs for a TEC.
7	User-Friendliness	-	Is the Cut-in/out Velocity slider working for TECs?
8	Value	-	The inputs look like they cover those we would normally use fairly well, however we are unsure of the exact input definitions in a few cases.
9	Value	-	Undecided if we would recommend the use of this software, until we see how fits into other modules and produces results.
10	General remarks	-	Cp/Ct curve is rather strange – for a free stream TEC I would expect Cp to max out well below the Betz limit of 0.593?
11	Usability	-	I could not use the Save Data button
12	Usability	-	There was no output, even to allow the user to check inputs
13	Usability	-	I found inputs for RM1 really weird
14	User-Friendliness	-	It seems that the purpose for the "logs" button is for debugging, but thus should be removed
15	User-Friendliness	-	I was sometimes redirected to the list page when submitting inputs
16	User-Friendliness	-	Remove underscores from material names in general inputs
17	User-Friendliness	-	When not in full screen, the text is unreadable 

ID	Feature	Subject	Comments
18	User-Friendliness	-	I was surprised to see this, as I was running a TEC scenario 
19	User-Friendliness	-	Min installation water depth can be superior to max installation water depth, and "number rotor" (this should be renamed…) can be 0, with no error message
20	User-Friendliness	-	Giving another title than "Study ID: 21 Page" for the pages would help the user
21	User-Friendliness	-	When clicking on the Inputs link at the top of the page, the page where the user is redirected has no interest: 
22	User-Friendliness	-	I could not easily provide the Cut In and Cut Out values: 
23	User-Friendliness	-	It takes a while to access the Inputs -> Model page, and the Output page and the Save Data button (this last never responded). When nothing can be done about it, maybe adding a message so that the user is aware the page is loading would be great.
24	User-Friendliness	-	With complexity level 3 for TEC, the last value for the Ct curve did not display, and as I had no feedback, there was no way to know if the value was taken into account or not, and I suggest to add axis titles with units: 

ID	Feature	Subject	Comments
25	User-Friendliness	-	The plus and minus buttons for the heading angles is not really relevant, with only angles only varying by 0.1° per click 
26	User-Friendliness	-	Whenever coordinate systems are used (e.g. interdistance, or heading span), display a Figure with the definition
27	User-Friendliness	-	When specifying more than one rotor for "Number Rotor", which I expect to be the number of rotors per device, I suggest allowing the user to give rotor coordinated (as rotors may not always be set in the horizontal axis, transverse to the flow, but could be vertically on a pile for example)
28	User-Friendliness	-	Maybe explain the "constant power factor", how the input will be used (should it be the maximum, the mean?), and if precision will be added to this constant parameter in the other modules according to the complexity level
29	User-Friendliness	-	The help panel is a good idea, but is not really visible, and more important, completely useless with regard to inputs to be provided...
30	User-Friendliness	-	When creating a project, a warning message displays "No general data has been saved for the Project ID 21", which could be deleted when accessing for the first time to the input page
31	User-Friendliness	-	Trust coefficient is thrust coefficient (I hope)
32	User-Friendliness	-	Adding the unit for material quantity, and the main dimensions would be great
33	User-Friendliness	-	The title "Operations" for the last column is weird, maybe remove the title
34	User-Friendliness	-	It is not clear how interdistance will be used in the general and model pages. Indicate if this is the distance between rotor for this two rotors-device, or the distance to accommodate when designing the array.
35	User-Friendliness	-	More guidance should be provided relative to main dimensions, there is no way to know what is expected (e.g. if the intent is for LMO, maybe having the dimensions for the biggest assembly supposed to be lifted would be necessary, or if these dimensions should be used in formulas, like power coefficients).
36	User-Friendliness	-	Efforts should be made on adapting inputs to complexity levels and type of technology (wet area or submerged volume for fixed tidal are not clear).
37	User-Friendliness	-	All the default values the software uses when the inputs are not provided by the user should be explicitly mentioned.
38	User-Friendliness	-	In a general manner, if inputs are not necessary to the study, for example in case the complexity level is low, it must be removed.
39	User-Friendliness	-	The draft must be provided but letting a value of 0 is accepted by the software, I don't know if this is normal.

ID	Feature	Subject	Comments
40	User-Friendliness	-	For complexity level 3, a Tip Speed Ratio is to be provided, but there is no guidance on how this will be used (is this supposed to be the optimal TSR for normal operation? Why to provide a single TSR and the whole performance curves?); When having a look at the technical note, the Cp coefficient for complexity levels 1-2 is different from any value in the U-Cp curve, there is no way to understand what is intended when providing a single value.
41	User-Friendliness	-	Number Rotor (-) may be changed to a more meaningful title (is this the number of rotors per device?).
42	Performance and Accuracy	Study Management	If the output section is available for WEC and TEC, even only for complexity level 3, it would be great to have feedback that inputs were correctly considered.
43	Value	-	Allowing the user to specify multiple rotor diameter for a single device heading may be appreciated.
44	Value	-	No error message is displayed when some inconsistent inputs are provided.
45	Value	-	Much more Figures and guidance to help the user are needed.
46	General remarks	-	The maximum Cp coefficient for the RM1 device is 0.62 in the technical note, this is above Betz limits, thus surprising.
47	Usability	-	Export was not working when I tested it (maybe that was due to the slow server?)
48	Usability	-	Some inputs are not clearly defined yet: • Definition of draft • Sign of water depth is negative in the documentation • Moment of inertia/cog/euler angles could not be defined (the GUI will put 1.0 whatever we type in the field)
49	Performance and Accuracy	Study Management	So far, I could not test a real case because of the moment of inertia equal to 1.0
50	Performance and Accuracy	Outputs: Efficiency	This is a field that you have copied/pasted from Spey I guess
51	Value	-	We cannot compare one study with another in MC module at this stage. But this is a difficult functionality to implement, so I am not sure we can expect this to be implemented in this project.
52	Value	-	I would like to have additional results displayed in the GUI: hydrostatic matrix (including restoring forces from buoyancy force AND gravity force)
53	General remarks	-	Special congratulations for the clear and well-organized GUI.
54	General remarks	-	Regarding the mesh: maybe indicate that the symmetry axes are defined in the mesh file.
55	General remarks	-	Fix the problem with inputting the moment of inertia, cog or euler angles (unit of angles. Note: moment of inertia can be positive or negative in practice.
56	Usability	-	Tables for representing results could be useful to have.
57	User-Friendliness	-	Some pop-up help could be useful for a quick understanding of the variables. An indication about the sign to be used to input the draft values.

ID	Feature	Subject	Comments
58	Performance and Accuracy	-	Computational time seems a bit too high. Optimal processor and memory requirements should be provided in order to give the users details about the computer to use and to plan simulation launches (e.g. to run in the evening to get results in the morning).
59	Value	-	An output file could be useful to have for comparing results for example for carrying out a sensitivity analysis about a parameter (e.g. to make a graph superimposing radiation damping changing diameter of the prime mover…)
60	Usability	-	Editing and save (in the sense of submitting inputs for every stage of the project) is very easy, but maybe the word 'save' should be substituted with 'export' because this is the functionality that actually allows the user to export a project.
61	Usability	-	Due to some problems with the server, was not possible to output the results for WEC3.
62	Usability	-	There were some statements difficult to rate because, not being able to see the results, it is difficult to judge the speed of computation and there was no need for the user to install the software on his computer.
63	User-Friendliness	-	Maybe the user could be more guided throughout the process. Especially when it comes to the selection of the mesh, some text boxes with information for the kind of mesh to be selected might be useful.
64	User-Friendliness	-	Unfortunately, the visualisation of the results was not possible. 
65	Performance and Accuracy	-	This section was almost impossible to score, not having seen the results
66	Value	-	It might be useful for the user to compare different scenarios.
67	Usability	-	Globally, the software is intuitive, and the training sessions were useful to understand how to use the software.
68	User-Friendliness	-	The main point to be improved to my mind is the interface: the software is really good, but the interface doesn't really look professional

9.3 ENERGY CAPTURE (EC)

Scores

TABLE 9.11: USABILITY OF EC

ID	Statement	Resp. 1	Resp. 2	Resp. 3	Resp. 4	Resp. 5	Resp. 6	Resp. 7
1.1	The software is intuitive and easy to use in general	5	4	4	4	5	4	5
1.2	It is easy to create and delete a Study	5	5	5	5	5	5	5
1.3	It is easy to edit, save and export a Study	5	3	5	4	5	4	4
1.4	The process of inputting data is clear and efficient	5	3	4	5	4	5	5
1.5	Results are meaningful, easy to interpret and use	5	4	3	4	4	4	5
1.6	I could complete the process without errors	5	5	3	5	5	5	5
1.7	I am satisfied with the overall speed of computation	4	5	5	5	5	5	5
1.8	The software can be run from my computer without any issue	4	3	5	5	5	5	5
1.9	The training sessions and documentation are useful for learning how to use the software	5	4	4	5	5	4	5

TABLE 9.12: USER-FRIENDLINESS OF EC

ID	Statement	Resp. 1	Resp. 2	Resp. 3	Resp. 4	Resp. 5	Resp. 6	Resp. 7
2.1	The user interface is simple, easy to navigate and well-organised	5	4	4	4	5	4	5
2.2	The user interface looks professional	4	2	4	3	3	4	5
2.3	It responds promptly to user actions (inputs, selections, clicks, ...)	5	4	5	5	5	5	5
2.4	It provides the user with enough help, indications and/or guidance throughout each process	3	2	3	4	4	4	5
2.5	The meaning of each data input/user selection is clear	5	2	3	5	4	5	5
2.6	The meaning of each data output is clear	4	4	3	5	5	4	4
2.7	Visualisation of results is clear and informative	5	3	3	5	5	5	5
2.8	The user can add further information to the Study through the interface	-	2	5	4	4	5	4

TABLE 9.13: PERFORMANCE AND ACCURACY OF EC

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

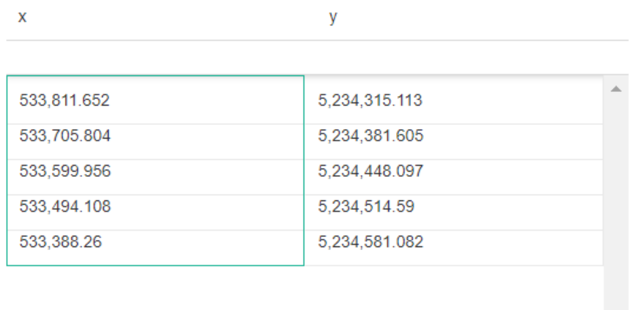
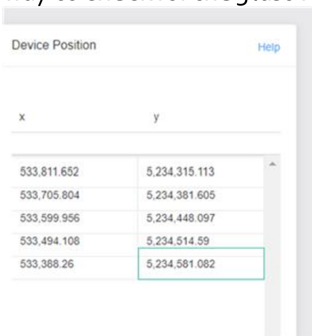
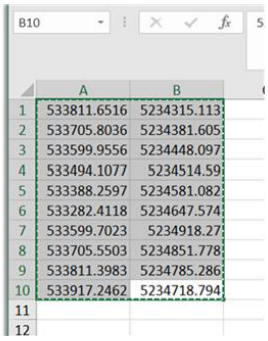
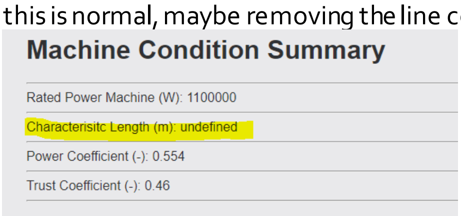
Fully aggregated results have been analysed without differentiating scores between VSs and functionalities. In all cases the average value per statement has been considered.

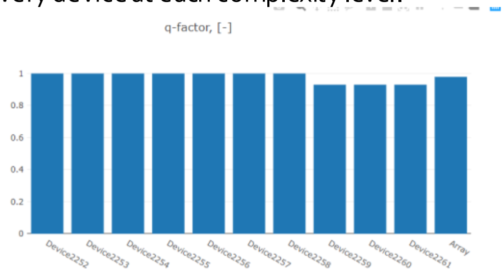
TABLE 9.14: VALUE OF EC

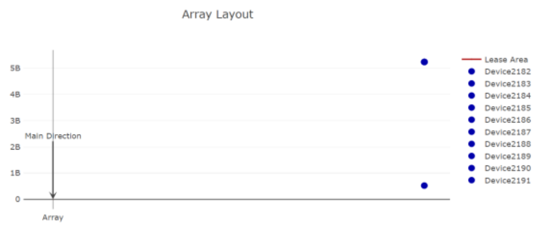
ID	Statement	Resp. 1	Resp. 2	Resp. 3	Resp. 4	Resp. 5	Resp. 6	Resp. 7
4.1	The software allows the user full control of the design process	5	3	4	5	5	5	4
4.2	It produces results that allow easy comparisons	5	4	4	5	4	4	4
4.3	It provides a large range of alternatives to create/assess technologies	5	3	4	5	5	5	4
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies	2	3	4	3	4	3	5
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality	4	3	3	5	5	5	4
4.6	I would recommend the use of this software	4	3	3	5	5	5	5

Comments

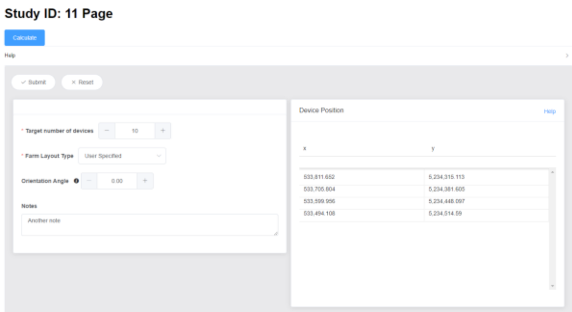
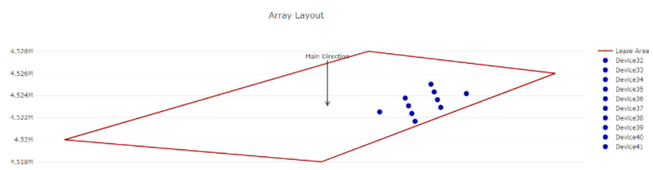
TABLE 9.15: COMMENTS FOR EC

ID	Feature	Subject	Comments
1	Usability	-	"Go Back" and "Next" buttons could be added, for the user to navigate smoothly
2	Usability	-	Exporting was not allowed
3	Usability	-	When trying to input the array layout, I copy pasted the data from the Excel, but could not delete any data then, even with the reset button 
4	User-Friendliness	-	The title of the study: "Study ID: 32 Page", could be modified
5	User-Friendliness	-	"Trust" coefficient could be changed to "thrust"
6	User-Friendliness	-	In the array layout section, even if I targeted 10 devices, only 5 rows would appear for complexity 1 and 3, and there was no way to check for the 5 last values: 
7	User-Friendliness	-	Values should be rounded to a reasonable digit to avoid unreadable outputs
8	User-Friendliness	-	The help message is not helpful, I am not sure this is intended to be kept identical: "Consistent within the interface: all elements should be consistent, such as: design style, icons and texts, position of elements, etc. »
9	User-Friendliness	-	The summary for site conditions is a good idea, but a visual description could be even better, with a map displaying.
10	User-Friendliness	-	Characteristic length is not defined for complexity level 2. If this is normal, maybe removing the line could be great: 

ID	Feature	Subject	Comments
11	User-Friendliness	-	When providing a complexity level 2 SC file for a complexity level 3 study, the error message is not friendly at all {"message":"Input schema validation error: {'soil_characteristic': ['Missing data for required field.'], 'blockage_ratio': ['Missing data for required field.'], 'V': ['Missing data for required field.'], 'X': ['Missing data for required field.'], 'Y': ['Missing data for required field.'], 'power_law_exponent': ['Missing data for required field.'], 'SSH': ['Missing data for required field.'], 'TI': ['Missing data for required field.'], 'probability': ['Missing data for required field.'], 'bathymetry': ['Not a valid list.'], 'U': ['Missing data for required field.'], 'velocity_field': ['Unknown field.']}","status":"error"}
12	User-Friendliness	-	Does the ID (#) for complexity level 3, tidal, refer to the bin in the site condition summary? It should be clarified
13	User-Friendliness	-	Json files are hard to use when the format is not explained to the user, a pre-processor should be created for users of the standalone mode.
14	User-Friendliness	-	Coordinates are not easy to interpret, with units and rounding that are not friendly 
15	User-Friendliness	-	Output for AEP are given in billions Wh, GWh would be better
16	User-Friendliness	-	It is possible to write notes, but nothing appears in the outputs section.
17	Performance and Accuracy	-	There is no easy way to know if the results are credible and trustworthy for the audience, input data was hard to understand. But I found q factors for three devices that were not equal to 1 for complexity level 2, though 1 is expected for every device at each complexity level. 
18	Value	-	It would be great to allow the user to specify the orientation angle for each tidal device in a farm.
19	Value	-	This may be a comment for the site characterization module: Allowing the current to vary in intensity and direction within a site would be appreciated (I could not see if this was the case in the current version as inputs are impossible to read). Then displaying the intensity and direction for each device would be great in the output section of EC.

ID	Feature	Subject	Comments
20	Usability	-	Need better input and output labels including units, and perhaps info. pop-ups or link to a reference document to what each term precisely means. E.g., 'q-factor' definition on Output graph?
21	Usability	-	Excel drops zero's on TEC position lat/longs when directly copied and pasted – error not caught by software and led to some head-scratching!
22	User-Friendliness	-	Maybe it would be useful to include direct links to a glossary or appropriate page of user manual, e.g. 'q-factor' definition on Output graph?
23	User-Friendliness	-	'Power Coefficient (-): 0.5549722' That's a very high Power Coefficient?
24	User-Friendliness	-	Labels on output graphs/graphics?
25	User-Friendliness	-	Visualization issue as indicated in documentation arose - clicking on the farm view and go back to the site view, solved the visualization problem. Works with this fix…
26	User-Friendliness	-	Not sure array layout output graphic working in any RM1 scenario? 
27	Performance and Accuracy	-	Only calculation for TEC is Annual Energy Production (AEP)?
28	Performance and Accuracy	-	AEP calculation looks correct for x1 or x10 1.1MW TECs – once I noted 'B' is for billion! Might be worth calculating and displaying output as the more useful MWh or GWh?
29	Value	-	The basic inputs look like they cover general requirements ok.
30	Value	-	Seems there are still quite a few input & output visualisation errors, so difficult to presently judge this?
31	Value	-	Undecided until we see how fits into other modules and produces results.
32	General remarks	-	Cp/Ct curve is rather strange – for a free stream TEC I would expect Cp to max out well below the Betz limit of 0.593?
33	General remarks	-	The study title is not properly displayed when in the study pages – "Study ID: 28 Page" etc. rather than actual title.
34	Usability	-	Maybe we can set directly the name of the study instead of "Study ID: X Page".
35	Usability	-	The software is very easy to use.
36	Usability	-	It would be good to set an option to import a study from existing files.
37	Usability	-	Training sessions were again useful.
38	User-Friendliness	-	The user interface could be more professional (graphical aspect), but the tool is really intuitive.
39	Performance and Accuracy	Study Management	Maybe we can set an indicator of the remaining time for the calculation.

ID	Feature	Subject	Comments
40	Performance and Accuracy	Inputs Collection	The data and inputs are easy to understand
41	Value	-	Maybe improving the comparison between two studies as it can't be done directly for the moment.
42	General remarks	-	Thanks for this software, it's a great work even if there are still some details to improve.
43	Usability	-	The title of the study should be presented in the top of the page, instead of "Study ID: X Page"
44	Usability	-	The software is very easy and straightforward to use.
45	User-Friendliness	-	The name of the outputs should be more explicit, instead of AEP and q-factor.
46	User-Friendliness	-	The user interface could look more professional, but it is very user-friendly.
47	Performance and Accuracy	Study Management	The message "calculating the results", could have an estimation of the remaining time for the calculation.
48	Performance and Accuracy	Inputs Collection	The data format is easy to understand
49	Value	-	The comparison between studies didn't look direct, the user must collect the results independently and then compare them.
50	General remarks	-	The software looks consistent and robust.
51	Usability	-	Exporting the study is not possible, but the warning message explaining it will be developed later is a good touch.
52	Usability	-	When implemented, the option to import a study from a file will be very welcome.
53	Usability	-	Very convenient to copy device position table from the spreadsheet, instead of filling one by one. Nice.
54	Usability	-	Visualization of array layout was greatly improved. This 3-d view looks good
55	Usability	-	Would be great to have explanation/help button describing what the q-factor is.
56	Usability	-	VS1VC1: Once the results have been calculated, the "calculating the results" message should disappear.
57	Usability	-	I would introduce the vertical axis label for the AEP. Also, I know this might go against what was discussed before, Wh seems a bit small unit for AEP. Maybe represent in kW (even though calculations use Wh)?
58	Usability	-	Does the "Main Direction" arrow represent the main current/swell direction? Would be nice to have this specified, as well as the direction in compass coordinates.
59	Usability	-	VS1: Surprisingly fast speed, even for CPX3. For VS2_VC3 (CPX3), a message warning user of expected computational speed should be included (even though it's below 1min, it's a case which takes much more time to run when compared to tidal tests).
60	User-Friendliness	-	In the study list, the column widths could be improved, namely placing everything on a single line as it looks unformatted.

ID	Feature	Subject	Comments
61	User-Friendliness	-	A message warning user of expected computational speed should be included (even though it's below 1min, it's a case which takes much more time to run when compared to tidal tests).
62	User-Friendliness	-	The capture width plot could be explained, as well as the objective of the notes (using a help/info hover button).
63	User-Friendliness	-	Q-factor could be briefly explained.
64	Performance and Accuracy	Study Management	The results were not evaluated in respect to accuracy, but they look credible.
65	Performance and Accuracy	Study Management	The software dealt well with incorrect input files.
66	Performance and Accuracy	Inputs Collection	Noticed that when going back to the Farm inputs (e.g. VS1VC2), the device positions do not show the entire list of devices (it should show 10 devices). Changing the target number of devices (to 9 and then back to 10) fixes this. 
67	Performance and Accuracy	Inputs Collection	Not sure what the notes do. Will they be compiled in a report or just stay there in the window?
68	Performance and Accuracy	Inputs Collection	When pressing the "calculate" button, would be nice to check whether any input has not been submitted yet. When running multiple times changing just one input, sometimes I forgot to submit the device position inputs before running.
69	Performance and Accuracy	Inputs Collection	The tool handles well the representation of devices located outside the lease area are introduced, however I believe a warning should be presented.
70	Performance and Accuracy	Inputs Collection	In VS1VC3, a blank machine capture width ratio plot is presented to the user in the input page. Confused why this is (happens for VS1 and VS2 test cases).
71	Performance and Accuracy	Inputs Collection	For VS2VC1, I was confused by this array layout on the lease area. Is this right lease area boundary closer to shore? How made this layout happen? 

ID	Feature	Subject	Comments
72	Value	-	Comparison between studies functionality not well implemented (even though this will be implemented on a higher level, I'm just letting this here for consistency with the other modules)
73	Value	-	Remaining time should be presented to user.
74	General remarks	-	Overall the tool looks and works really well. Congratulations!
75	User-Friendliness	-	We tried to change device coordinates for launching different cases and observe the effects on q-factor but the software crashed.
76	Value	-	The graph Capture Width Ratio shows ordinates number like "2M": is it meters? Shouldn't be %?

9.4 ENERGY TRANSFORMATION (ET)

Scores

TABLE 9.16: USABILITY OF ET

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

TABLE 9.17: USER-FRIENDLINESS OF ET

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

TABLE 9.18: PERFORMANCE AND ACCURACY OF ET

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

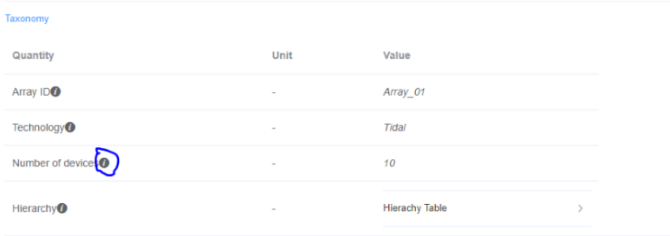
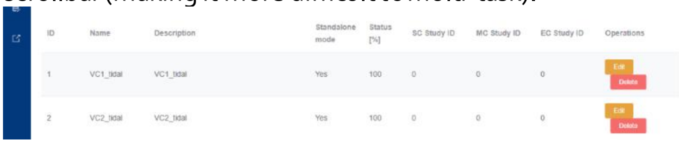
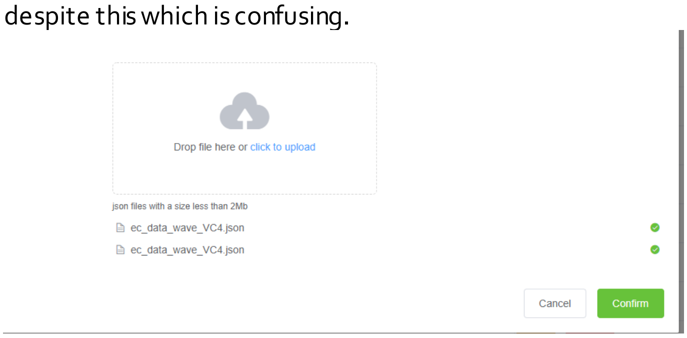
Fully aggregated results have been analysed without differentiating scores between VSs and functionalities. In all cases the average value per statement has been considered.

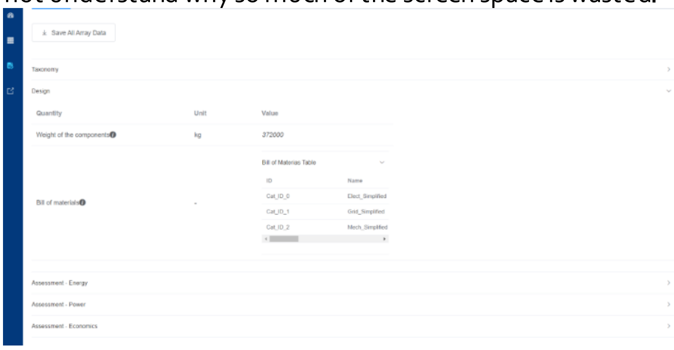
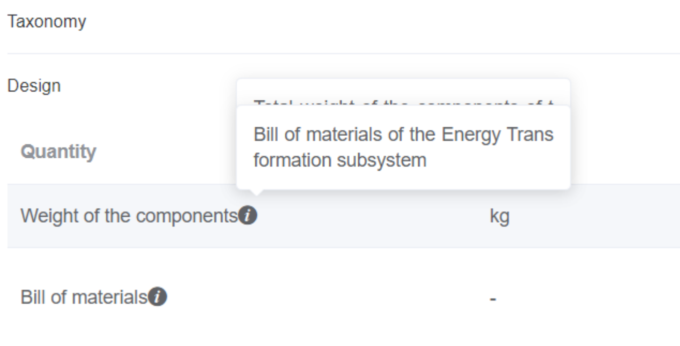
TABLE 9.19: VALUE OF ET

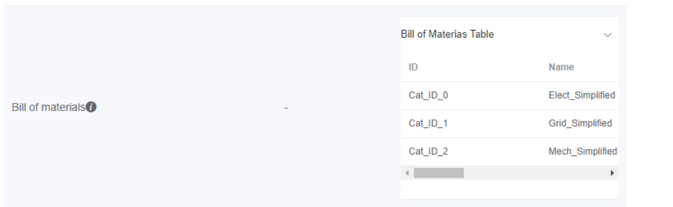
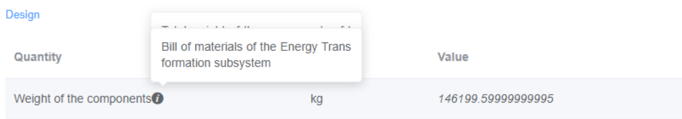
ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
4.1	The software allows the user full control of the design process	4	4	4	2	5	5
4.2	It produces results that allow easy comparisons	4	5	1	4	4	5
4.3	It provides a large range of alternatives to create/assess technologies	4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

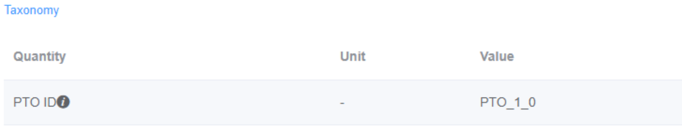
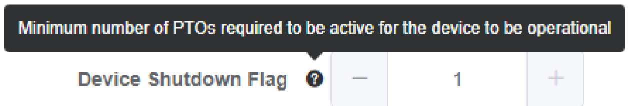
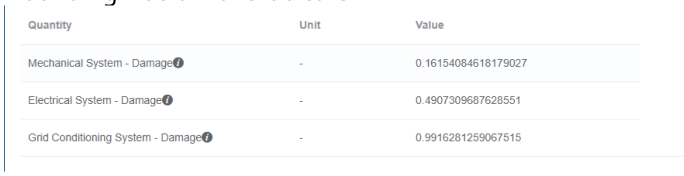
Comments

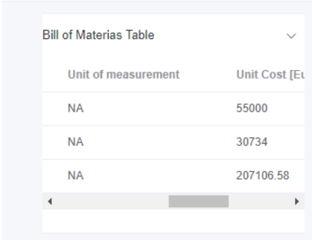
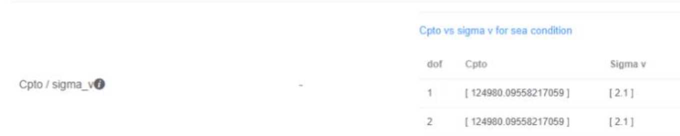
TABLE 9.20: COMMENTS FOR ET

ID	Feature	Subject	Comments
1	Performance and Accuracy	Outputs: Array/Device/PTO Outputs	Please double check the "info" (see image below) provided in each output. In some cases, it isn't correct. Taxonomy -> Hierarchy table isn't giving any information. 
2	User-Friendliness	-	The GUI is different from other modules. For example, when creating the study, you have to upload files. Although it is intuitive, it is not what the user expects after having used other modules.
3	Usability	-	The overall interface requires far too many clicks with most things hidden for no clear reason. This seems to apply to all modules.
4	User-Friendliness	-	The duplication of the studies across both the ET Studies & Analysis mode pages is slightly confusing, could the links to select/outputs be on the studies page?
5	User-Friendliness	-	The list of studies does not make good use of the available space, needing a wide window to remove the horizontal scrollbar (making it more difficult to multi-task). 
6	User-Friendliness	-	The Outputs button should be disabled if there are no outputs calculated.
7	User-Friendliness	-	When creating a study without a unique name the inputs are lost. The user should be able to change the name and not need to re-enter all the data.
8	User-Friendliness	-	If I add multiple studies consecutively, the filenames are still shown in the upload boxes, but I need to add the file again despite this which is confusing. 

ID	Feature	Subject	Comments
9	User-Friendliness	-	On the input data page, why is everything hidden to begin with? I understand grouping things together, but it would be much more usable if everything were visible and I could just scroll down.
10	User-Friendliness	-	Power should be in kW or MW so there are not so many 000 to type (easy to enter 30kW instead of 300kW)
11	User-Friendliness	-	Not clear why the rated power is entered 3 times for mechanical, electrical, and grid conditioning. It would be helpful if the pre-filled value for the later 2 was the same as entered in the first box, rather than typing it 3 times.
12	User-Friendliness	-	For the help on Electrical conversion class, it would be useful to have a summary of what A/B/F/H mean. Similarly, explain what the cosfi (cosphi?) parameter is.
13	User-Friendliness	-	The results pages are very difficult to navigate. If I click taxonomy then hierarchy table it just hides all the results, I cannot see this result.
14	User-Friendliness	-	The BOM is mostly hidden with an unnecessary scrollbar, I do not understand why so much of the screen space is wasted. 
15	User-Friendliness	-	Using json format for the export of results is not very user friendly, it would be nice to have csv format for the data too.
16	Performance and Accuracy	Inputs Collection	For VC2, the Device Shutdown Flag can be set at 0 or 1. I don't understand how the device can be considered to be active with 0 PTOs active? Should this be the number failed?
17	Performance and Accuracy	Outputs: Array/Device/PTO Outputs	The results should not display unwarranted precision, e.g. 'weight of the components' specified to the nearest 10^{-8} grams! Nearest kg would be more than precise enough.
18	Performance and Accuracy	Outputs: Array/Device/PTO Outputs	The help for 'bill of materials' obscures that for 'weight of the components' 

ID	Feature	Subject	Comments
19	Performance and Accuracy	Outputs: Array/Device/PTO Outputs	I would have expected a percentage loss at each stage would be calculated as part of the assessments.
20	Performance and Accuracy	Outputs: Array/Device/PTO Outputs	Plots of the results would be better to be visualise the energy assessment etc.
21	Performance and Accuracy	Outputs: Array/Device/PTO Outputs	The power assessment requires 6 clicks to view and has so much white space that it does not all show on my screen at once. This should be one table with rows for condition and columns of mechanical, electrical, grid power etc.
22	Performance and Accuracy	Outputs: Array/Device/PTO Outputs	Similarly, in the device outputs page could these not be tabulated (and preferably plotted) so that it is possible to compare between devices in the array.
23	Performance and Accuracy	Outputs: Array/Device/PTO Outputs	For the PTO outputs, if there is only 1 PTO per device it should be selected by default.
24	Value	-	The tool has a very comprehensive set of options, but as I am not an electro-mechanical engineer, I cannot comment on the exact scope of these.
25	Value	-	The tool could provide feedback if the design is poor, e.g. if the power rating of the gearbox was far from optimal resulting in a very inefficient design with high losses.
26	General remarks	-	Overall, the tool is powerful, but let down by a confusing and not very user-friendly GUI that requires many clicks to reveal inputs/results and makes it difficult to visualise and compare outputs.
27	Usability	-	I suggest to simply remove the line for "Machine Characterisation study" in the "Create an Energy Transformation study", as long as the user has not provided the first two json files. It looks like a bug.
28	User-Friendliness	-	Steps when clicking on the "-" and "+" buttons need to be adjusted to relevant values for the parameter considered (e.g. adding 1 unit to a 1000000 basis is not useful)
29	User-Friendliness	-	I found confusing to have split the "ET Studies" and "Analysis mode"
30	User-Friendliness	-	The layout could be improved, and "materias" corrected to "materials": 
31	User-Friendliness	-	Problem with the display of the help messages: 

ID	Feature	Subject	Comments
32	User-Friendliness	-	The taxonomy panel could be removed to be directly integrated in a title for the section: 
33	User-Friendliness	-	Brackets may be removed: 
34	User-Friendliness	-	In the “Analysis mode” window, clicking on the “select” button to access the study never worked the first time, but worked immediately after refreshing the page.
35	User-Friendliness	-	The hierarchy table for the array never displays in the taxonomy section.
36	User-Friendliness	-	I would find useful to add more guidance relative to the following point: “In case of updating the external modules, again, upload the files in the proposed order (EC, SC and MC). If not all the files are to be uploaded, ensure that if EC file is updated, MC is uploaded again even if the file is the same. This is because the tool updates the internal variables during the MC upload.”
37	User-Friendliness	-	I suggest to clearly display to the user what default values will be considered for each transformation step, for the complexity level used.
38	User-Friendliness	-	Warning the user about the complexity levels used for the various inputs from GUI, catalogues and other modules, if they are compatible, and what they allow to achieve (eventually referring to section in documentation).
39	User-Friendliness	-	Maybe stating more clearly what “active” and “operational” mean and renaming “Device Shutdown Flag” to something clearer. 
40	User-Friendliness	-	I suggest to precise the period used to estimate all the values in the output section (energy, damage…)
41	User-Friendliness	-	Rounding would make it clearer: 

ID	Feature	Subject	Comments
42	User-Friendliness	-	I don’t understand the intent for the Unit of measurement (if no values are provided, I suggest to delete it) in the following table:  Bill of Materias Table Unit of measurement – Unit Cost [Eu NA – 55000 NA – 30734 NA – 207106.58
43	User-Friendliness	-	Cpto / sigma_v should be defined to the user, this is not widely used. The help message never displays here:  Providing the formula for the Damage in a help panel could be great, with expected magnitudes.
44	Performance and Accuracy	Outputs: Array/Device/PTO Outputs	We had no baseline to assess the results
45	Value	-	About the mechanical transformation type: I suggest to add the option for a direct drive powertrain (i.e. no gearbox), or at least not having reliability or cost issue coming from a gearbox with a ratio let to unity if we account for a direct drive solution.
46	Value	-	About the electricity transformation type: - I was surprised that the only possibility for the electrical transformation feature was SCIG, as tidal turbine developers mainly use PMSG and DFIG generator. - Maybe having two rated powers, one for the generator side, and one for the Active Front End side could be great - We suggest to have “S1 Rated Power” instead of “rated power” (and eventually S2…S10 for high complexity levels) - We suggest to allow the user to provide tabular bidimensional inputs to define the generator efficiency, as a function of speed and torque for a given generator (maybe with distributions associated to the torque and speed encountered in each sea state provided by the EC module) - We suggest to rename “maximal to nominal torque”, which may be confusing, to “peak to nominal torque”, as maximum is sometimes a quadratic average, or time-averaged value - In case a PMSG option is offered, the flux weakening control allows a non-constant maximum to nominal voltage, and two inductances could be provided, Ld and Lq, depending on how magnets are mounted

ID	Feature	Subject	Comments
47	Value	-	About the grid conditioning inputs : - We suggest to add the line filter inductance, resistance, capacitance, along with the type of filter (L, LCL, dvdt) - We suggest to add the capacitance at the output of frequency converters, and for the DC bus, which affects damping
48	Value	-	We suggest to add in the catalogues Semikron IGBTs, and new models made of silicon carbide materials, as they are expected to play an important role in the future years
49	Value	-	I was not expecting the control strategy to be based solely on sea state, but I can understand the reason to opt for this easy approach
50	Value	-	Maybe giving the opportunity to the user to provide its own json file with components and associated data from a previously run study could be great
51	Value	-	When running the tool, a message could be displayed to inform the user that the calculation has begun and show the progress of calculation. I did not know if the module was working when clicking on "Run"
52	Value	-	If default values are used, they should be mentioned to the user.
53	Performance and Accuracy	Study Management	The cases were built in a rigid way: fixed point cases. For example, at the wave cases it was not possible to test array production by changing the sea state: we tried to change wave period by no power production changes occurred. No information about the selection of B_pto: was it the optimum value? How the passive control system acts with a single sea state verification case?
54	Value	-	The only change of damping factor produced some power production changes.
55	Value	-	It is desirable to evaluate and plot wec RAO or power against wave frequency range.
56	Usability	-	Globally, the software is intuitive and the training sessions were useful to understand how to use the software.
57	User-Friendliness	-	The main point to be improved to my mind is the interface: the software is really good but the interface doesn't really look professional.

9.5 ENERGY DELIVERY (ED)

Scores

TABLE 9.21: USABILITY OF ED

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

TABLE 9.22: USER-FRIENDLINESS OF ED

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

TABLE 9.23: PERFORMANCE AND ACCURACY OF ED

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

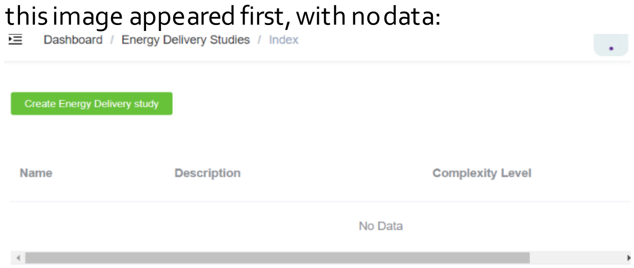
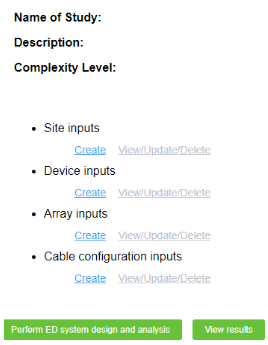
Fully aggregated results have been analysed without differentiating scores between VSs and functionalities. In all cases the average value per statement has been considered.

TABLE 9.24: VALUE OF ED

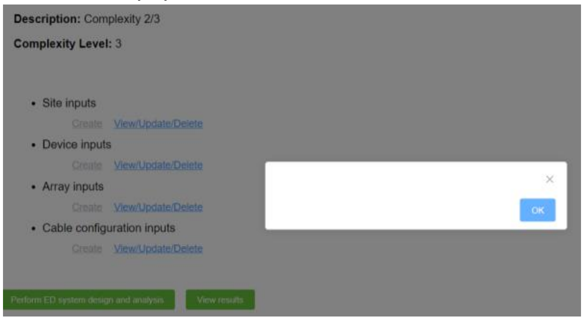
ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5
4.1	The software allows the user full control of the design process	4	5	4	5	4
4.2	It produces results that allow easy comparisons	4	3	5	4	4
4.3	It provides a large range of alternatives to create/assess technologies	3	5	5	5	4
4.4	The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

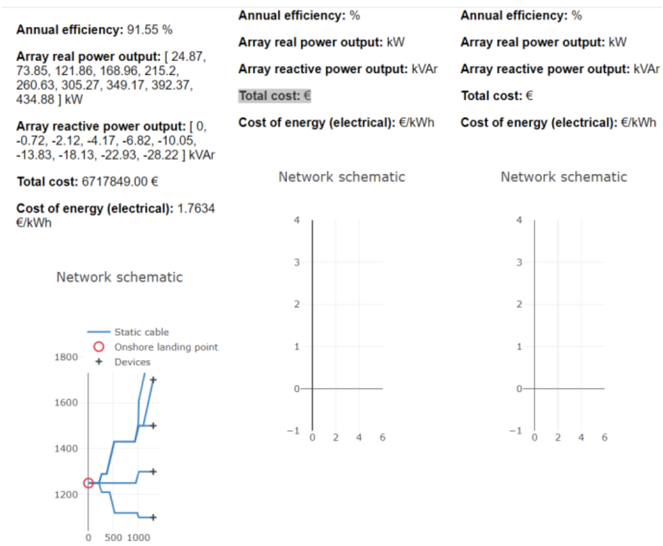
Comments

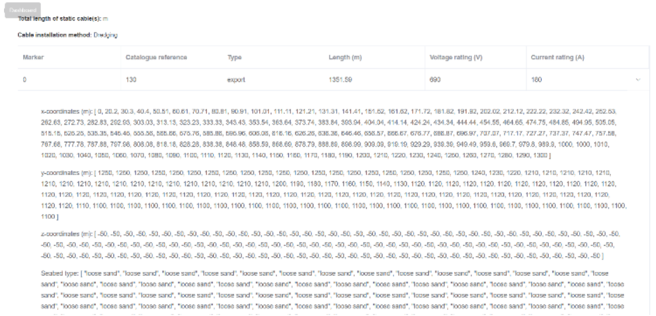
TABLE 9.25: COMMENTS FOR ED

ID	Feature	Subject	Comments
1	Usability	-	The technical note for the verification of ED is suitable.
2	Usability	Inputs	Change "Cable installation tool" to "cable installation method" as it seems more appropriate.
3	Usability	Inputs	Is there a distinction between CPX2 and CPX3 in respect to inputs? [*NOTE: no, there is not*]
4	Usability	Inputs	Case 2.2 inputting RM3 site files crashes my Edge and Firefox browsers (also legend is weird for reduced bathymetry file)
5	Usability	Inputs	Ability to export DR not available yet.
6	Usability	Inputs	Remove from the Array inputs page the "(m,m)" of the Array Device layout input as it is a json file
7	Usability	Design	Test files are now running, although a blank error message appears (now very unfrequently), possibly due to a timeout error.
8	Usability	Design	I noticed that once I have filled the inputs and left blank the "Footprint radius", which was automatically stored as "0" (zero). I could not replicate this behaviour, but I did notice that everytime the footprint radius is defined as zero, a timeout error shows up (blank message).
9	Usability	Inputs	Introducing a json file by hand is not extremely user friendly.
10	Usability	Inputs	I had problems to upload the site inputs. The interface is correct. I could not load site inputs, and therefore check its interface.
11	Usability	Inputs	Took a few refreshes of the page each time when accessing "Energy Delivery Studies", to see the list of studies. Usually this image appeared first, with no data:  The same when opening a study, the inputs were empty and took a long time to/didn't at all load: 

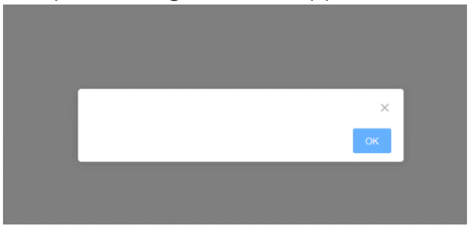
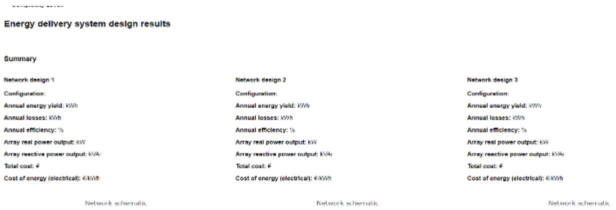
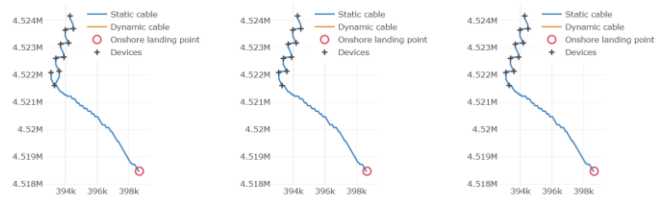
ID	Feature	Subject	Comments
12	Usability	Inputs	Relative to 1.2: If complexity levels 2 and 3 give the same results, maybe leaving it as "Complexity level 2/3" will prevent to confuse the users
13	Usability	Inputs	Relative to 1.4: - Providing a preprocessor to the user for him to easily convert usual format of coordinates to a json file could be useful - Providing coordinates (e.g. location of umbilical connection point) is not easy without the coordinate system provided, thus showing a Figure whenever coordinates are requested would be great. Three boxes for each coordinate would be better than the (x, y, z) format. - Json format should be avoided as much as possible, replaced when possible by manual entries in boxes (e.g.: Array device layout)
14	Usability	Design	Some tests take quite a while to run. Would be great to have a progress bar for the calculation to estimate time to end.
15	Usability	Results	Visualisation of the network schematic is very nice, although legend many times fits above the design. Maybe better zoom definitions would be good for legend placing
16	User-Friendliness	Inputs	It would be helpful to have some explanation about inputs (maybe one of those help buttons that expand a small help window with further info). Not all inputs are clear.
17	User-Friendliness	Inputs	I have been thinking about the option of copying/duplicating a study. This would come handy when testing slightly different studies. Maybe we can also expand this idea to other modules.
18	User-Friendliness	Inputs	Relative to 2.3: Inputting data is really long and there is no way to know if this has been taken into account
19	User-Friendliness	Inputs	Relative to 2.4: I would find useful to tell the user what calculation is done/default value is used whenever an optional input is not provided. The "Onshore infrastructure flag" is not clear at all.
20	User-Friendliness	Design	Relative to 2.1 [*The user interface is simple, easy to navigate and well-organised*]: Refusing to the user the access to the "View results" section should be considered, as there is no indication of the status/remaining time for the ongoing calculations.

<table>
<tr><th>ID</th><th>Feature</th><th>Subject</th><th>Comments</th></tr>
<tr><td>21</td><td>User-Friendliness</td><td>Design</td><td>When clicking on “Perform ED system design and analysis”, I had this empty box


[NOTE: this was due to the code bug described in section 4522]</td></tr>
<tr><td>22</td><td>User-Friendliness</td><td>Results</td><td>Relative to 2.7 : If only one network configuration is displayed, I suggest sections regarding to the other two are deleted

</td></tr>
</table>

ID	Feature	Subject	Comments
23	User-Friendliness	Results	The current form for the network hierarchy should be deleted as information is not clear to any unexperienced user 
24	User-Friendliness	Results	The "Marker" is referencing to something the user is not made aware of in tables
25	User-Friendliness	Results	Same can be said about the generated cable characteristics, an export to an Excel file would be better 

ID	Feature	Subject	Comments
26	User-Friendliness	Results	For the results: the units could be automatically updated to MW etc: **Configuration:** radial **Annual energy yield:** 142908493.61 kWh **Annual losses:** 1631506.39 kWh **Annual efficiency:** 98.87 % **Array power output:** [16313.75] kW **Total cost:** 36607707 € **Cost of energy (electrical):** 0.2562 €/kWh
27	User-Friendliness	Results	Going straight to the results the first time after performing analysis, instead of having to click "view results" would be more user friendly Perform ED system design and analysis View results
28	Performance and accuracy	Design	The application is not working, so assessing the accuracy of the results is difficult
29	Performance and accuracy	Simplified design mode	The simplified VCs ran really smoothly and was very easy to use, see results etc.
30	Performance and accuracy	Simplified design mode	Relative to 3.a.2: it was hard to tell as inputs in json files were complicated to deal with for a newcomer
31	Performance and accuracy	Full design mode	Relative to 3.b.1: I could not do some kind of sensitivity studies because analysis took a while to run.
32	Performance and accuracy	Full design mode	Relative to 3.b.3: I was expecting results for Umbilicals to be provided, as well as total length for static cables (as they are shown in the tables below)
33	Performance and accuracy	Full design mode	Wrong units in Array device layout input box? See below: **Create array inputs** *Please input location of landing point as (x, y) coordinates. e.g. (0,0). Please ensure thai no whitespaces in the input.* * Landing point (m,m) (0,1250) *Please input location of every device in the following JSON data format: e.g. {"deviceid": "easting": [1300,1150], "northing": [1250,1250]}* * Array device layout (m,m) { "deviceid":[1,2,3,4,5], "easting":[1300,1300,1300,1300,1300]
34	Performance and accuracy	Full design mode	I received multiple errors when trying to input site data, plotting and creating the site inputs. The data disappeared various times. • Site inputs Create View/Update/Delete • Device inputs Create View/Update/Delete • Array inputs Create View/Update/Delete • Cable configuration inputs Create View/Update/Delete Operation cancelled. Site inputs not stored in the database.

ID	Feature	Subject	Comments
35	Performance and accuracy	Full design mode	After running the analysis, some errors occurred. The analysis was performing, then this appeared:  Results show up as empty, even though all the inputs have been added:  [*NOTE: this was due to the code bug described in section 4.5.2.2*]
36	Performance and accuracy	Results	Does the first design of case 2.2 being identified as the best one surprise you? Do you have any comments as to why the first design makes more sense? 
37	Value	Inputs	This could be improved by introducing a progress bar and a loading bar for large input files. It seems that it will be the case for the site bathymetry files which are very slow to load.
38	Value	Inputs	Relative to 4.4: When clicking on the "Create" button, a loading bar could be displayed to the user as inputting data to the database is really long, and the user does not know if he can move to the next step
39	Value	Design	Some tests take quite a while to run. Would be great to have a progress bar for the calculation to estimate time to end
40	Value	Results	Comparisons between different network schematics is very useful.

9.6 STATIONKEEPING (SK)

Scores

TABLE 9.26: USABILITY OF SK

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

TABLE 9.27: USER-FRIENDLINESS OF SK

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

TABLE 9.28: PERFORMANCE AND ACCURACY OF SK

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	4	4	5	2
3.2	Results are credible and trustworthy for the audience	4	3	5	3	4	5
3.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used	4	4	4	4	5	5
3.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity	4	-	4	4	5	4
3.5	The computational time is adequate for the level of accuracy provided	3	4	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	5
3.7	The software can handle errors without crashing	5	5	5	5	5	5

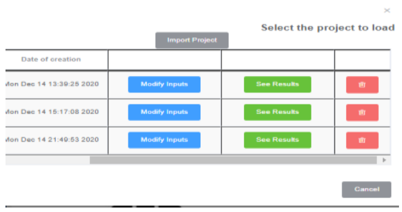
Fully aggregated results have been analysed without differentiating scores between VSs and functionalities. In all cases the average value per statement has been considered.

TABLE 9.29: VALUE OF SK

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

Comments

TABLE 9.30: COMMENTS FOR SK

ID	Feature	Subject	Comments
1	Usability	PDF export	I could not export results as PDF (there were issues, and the PDF kept being empty), though results were generated.
2	Usability	Documentation	The training session and material were really useful, and even essential because some inputs were not clearly defined in the tool itself. Nonetheless, it was particularly adapted to the VCs tested, but we may require further support to adapt to cases and situations from industrial partners. This is pointed out in the following sections.
3	User-Friendliness	-	Slight lags to go on next page with the "Next page" buttons
4	User-Friendliness	Documentation	A theory or user manual would be great for the early user to understand what is in SK and how are the rotor, the foundation modelled in SK, and what should come from other modules, because I found quite hard to know what should be included in masses, how a device, and a rotor are defined, what a foundation is, if a different name is used for the structure below and above seabed, etc… Some terms concerning turbine configuration like device or rotors could be presented in a help menu, for users who don't have time to read D5.6.
5	User-Friendliness	GUI tooltip	At this point (see below), we don't know if we are going to modify inputs from a previous study or create a new one, this may not be clear enough (maybe some guidance like "clicking here won't alter this study, if you run the model with a new project name") 
6	User-Friendliness	Input visualization	Even if this is quite intuitive in general, adding guidance about a number of inputs (Figure with rotor configuration currently defined, coordinate systems and origins for geometry, weather climate and forces, hub position…) could be useful
7	User-Friendliness	Documentation	Some more guidance on how these inputs are used (to help the user get why he has to provide the information) would be great, maybe with a redirection to a section in D5.6 or a user manual: for the wind force model, the current and mean wave drift force model, the directions (why is current always aligned with rotor axis?), how they are calculated and on which part of the device, structure, rotor, etc…
8	User-Friendliness	New functionality - backend	Rotor diameter: allowing for multiple rotor diameter could be great
9	User-Friendliness	Documentation	Weather direction: clarifying what is included: waves, current? Splitting those two could be great as the worst combination may not be when they are aligned.

ID	Feature	Subject	Comments
10	User-Friendliness	Documentation	Master structure: what it is, and how it used could be clarified
11	User-Friendliness	Documentation	How substation foundations inputs are defined, how they are used, etc…could be explained. Clarifying what modifying North/East position for substation would change could be great
12	User-Friendliness	Documentation	Maybe removing the soil definition or shading it when using gravity based structures could be helpful (and more generally all sections that won't be used in calculations, to help user know what is done by the SK tool)
13	User-Friendliness	Documentation/ GUI clarity	Explaining why shallow and gravity based are the same would help
14	User-Friendliness	GUI functionality	It could be good to display results somewhere else that in a log file, which is kind of hard to read.
15	Performance and Accuracy	New functionality - backend	It is complex to imagine a solution with a 1.3m thickness and 13m diameter (manufacturing constraints..), maybe it could be possible to have a compromise between setting all the dimensions and having all the dimensions set by the SK tool, which would be to give an acceptable range for each dimension in the automatic design mode
16	Performance and Accuracy	Documentation	I observed to difference in inputs whatever the complexity level I used (only in the master structure section), I don't know if this was a bug
17	Value	New functionality - backend	This point has already been discussed in informal calls: the choice is really limited to represent the geometry for support structures that are being used in the fixed tidal industry. The majority of developers don't use a huge cylindrical or pyramid-like structure as represented in the SK tool, but a metal frame with ballasts, that it would be great to represent.
18	Value	New functionality - backend	It seems that rotor is always considered facing the current (which is said in the presentation of VCs for SK, in the section defining weather direction). Some tidal developers use no yaw systems, so are permanently with non-zero angles if flood and ebb aren't aligned. It would be great to take this into account.
19	Value	New functionality - backend	I find it surprising not to add orbital velocity for the calculation of thrust on the rotor, as it may be an important contribution to limit loads
20	Value	New functionality - backend	Leading an FLS analysis on fixed substructures for tidal turbine would be useful. Reference standard exists (ISO19902, section 16 for example), though it may be harsh to implement the design criteria.
21	Value	Bug in GUI	It would be great to allow the user to specify another material than concrete
22	Value	Input visualization	It could be great to give some more visualization output for the user to ensure he provided what he expected, maybe with a Figure with the device(s), environment, sea level and seabed, coordinate systems, forces, etc…
23	Usability	Documentation	Type of foundation score calculated how/why would I trust this? Transparency is critical to decision making.

ID	Feature	Subject	Comments
24	Usability	GUI clarity	Could correct calculation manual section and glossary of terms (e.g. type of foundation 'shallow') be included as a direct link from SK software GUI?
25	User-Friendliness	Documentation in GUI	Including direct links to a glossary or appropriate page of user manual. E.g. definition of Hub position x, y, z?
26	User-Friendliness	New functionality - backend	*Foundation - Soil type* – is there a bedrock option? Important for tidal gravity foundations.
27	Performance and Accuracy	Documentation in GUI	Definitions and methodology should also be easy to access directly from GUI?
28	Performance and Accuracy	Bug in GUI	Output as per Foundation inputs in Section 2 above – deduce this is cylindrical concrete (*weight in air* which would be important to mention for all masses) from other results pages – can material be changed somewhere?
29	Performance and Accuracy	Input data check	Only threw in a few deliberate errors, not a comprehensive test! Can end up with interesting results e.g. if slope is set to 90 degrees – garbage in, garbage out
30	Value	Documentation in GUI	Likely a good basic screening but requires more transparency in suggestions and calculations. As per previous suggestions e.g.: Case RM1-SK-1 type of foundation score calculated how? Transparency is critical to trust in use and decision making.
31	User-Friendliness	GUI improvements	Only small point could be to improve the visual interface, to make it more "attractive" and professional.
32	Usability	Data input check	Error when defining current velocity outside thrust curve coefficient velocity range
33	Usability	Data input check	Warning when input data is missing
34	Value	New functionality - backend	In the Floating structure hydrodynamic into Device Properties, it should be interesting to have the possibility to load the mean drift wave forces from the potential flow hydrodynamic solver calculation.
35	Value	Documentation in GUI	It is not clear in the automatic design how the mooring system start point (in design assessment) is calculated.
36	Value	New functionality - frontend	It would be interesting to report the mooring's weights in the Design Assessment output

9.7 LOGISTICS AND MARINE OPERATIONS (LMO)

Scores

TABLE 9.31: USABILITY OF LMO

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	3	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	4	3	4	5	5
1.4	The process of inputting data is clear and efficient	3	4	4	3	5	5
1.5	Results are meaningful, easy to interpret and use	3	3	4	4	5	4
1.6	I could complete the process without errors	2	3	4	2	4	2
1.7	I am satisfied with the overall speed of computation	4	2	4	3	5	5
1.8	The software can be run from my computer without any issue	4	2	5	3	4	3
1.9	The training sessions and documentation are useful for learning how to use the software	4	4	5	5	5	4

TABLE 9.32: USER-FRIENDLINESS OF LMO

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

TABLE 9.33: PERFORMANCE AND ACCURACY OF LMO

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

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

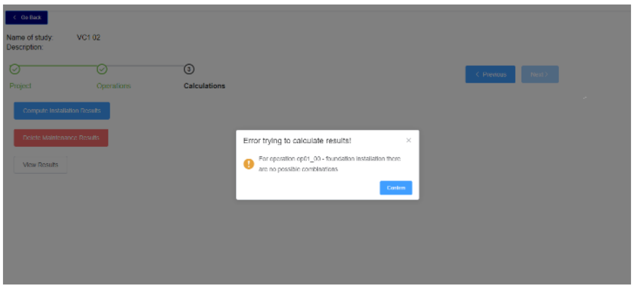
TABLE 9.34: VALUE OF LMO

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

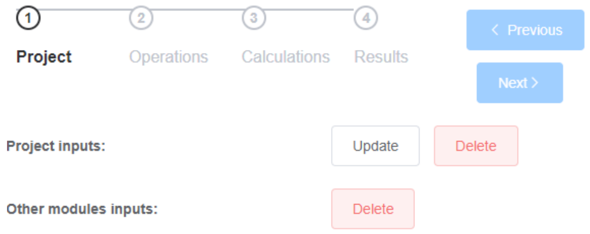
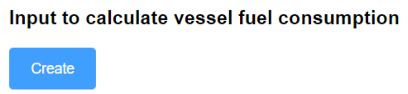
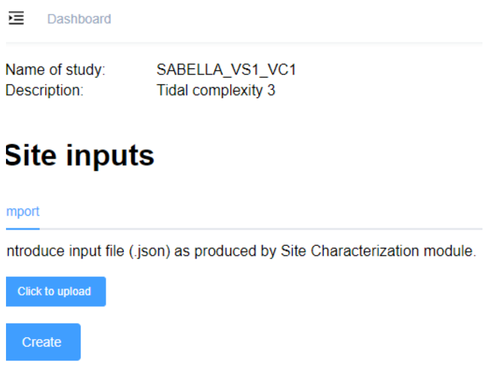
Comments

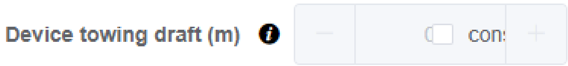
TABLE 9.35: COMMENTS FOR LMO

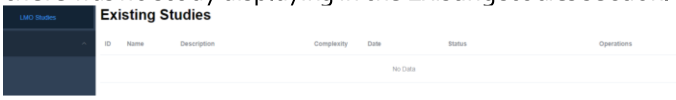
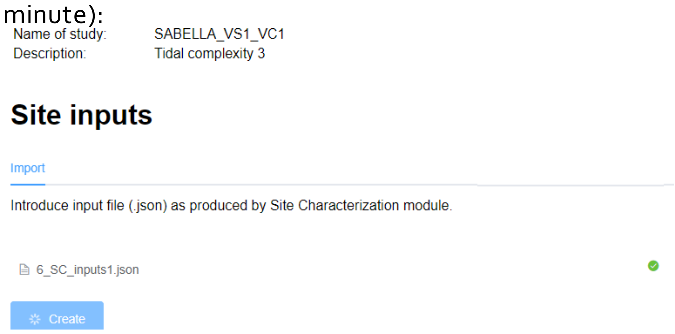
ID	Feature	Subject	Comments
1	Usability	General	It seems that the studies of different complexity levels must be created separately. It is not allowed to modify the complexity of an existing project and go on with the analysis.
2	Usability	General	It seems that the "Delete" button in Site inputs does not work. A message "LMO study with that ID does not have a site yet." pops up, when this button is clicked. In addition, if the "Update" button is pressed, the pop-up message is empty and cannot direct the user back to the interface "Project".
3	Usability	Installation	For Complexity 3, there is an error, when performing the installation analyses. The error occurred for all Complexity cases.
4	Usability	Maintenance	For Complexity 3, there is an error, when performing the installation analyses. The error message is "Name of study is incorrect. Please modify the name to VSX_VCY".
5	Usability	Maintenance	There are several repeated lines associated with "underwater inspection" and "export cable inspection". It is suggested to add a few notes briefly explaining what these repeated inspections refer to respectively?
6	Usability	Decommission ing	It is noted that the time of decommission for some components is hard to understand. For example, the start-up operation time is June-2021, however, the decommissioning time is June-2020. This may be caused by some errors in the previous steps.
7	Usability	-	Unit of measurement is missing in the output values.
8	Usability	-	There are many problems with the VS2-VC1. So we were only able to evaluateVS2-VC4.
9	User-Friendliness	-	The system did not respond promptly, the input time was sometimes very long.
10	Performance and Accuracy	Study Management	The data was not always visible to the user.
11	Performance and Accuracy	Study Management	After the insertion sequence, the system does not read the inputs (no delete). I try to insert them again but the system reports that they have already been entered.
12	Performance and Accuracy	Outputs: Installation solution	About the burial operation for cable installation: is the burial length 1800m long as the entire cable path?
13	Value	-	A logging while running the module would be useful to monitor the calculation steps, which is the bottlenecks and what are the warnings and errors that might occur.
14	Usability	-	More guidance on the GUI to help the user understand what the terminology means would be helpful. It was very straightforward with the training video, so some of that could be merged into the GUI.
15	Usability	-	It's not easy to edit a study – any time you click 'edit' it resets every input so it's starting from scratch.
16	Usability	-	In general, results are meaningful, easy to interpret and use – there could be some improvements like adding units to all parameters and making sure all headings on the results table and Gantt chart can be seen.

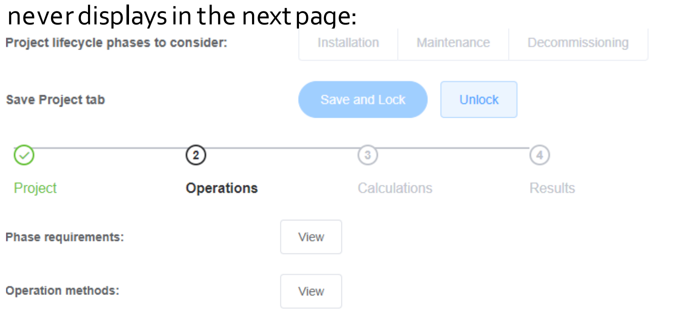
ID	Feature	Subject	Comments
17	Usability	-	A few errors/ bugs were present e.g. Having to refresh the Installation results page. Also, the installation calculations for VC1 02 were not able to run successfully. See error message below. 
18	Usability	-	For complexity level 1 everything runs in the order of seconds and is extremely efficiency. For complexity level 3 the timings for verification cases are: •VC1 01: Installation: 42mins; Maintenance: 12 - 23 mins •VC1 02: Installation: could not finish, led to bug above; Maintenance: 1hr 41mins In general, the timing is OK but the user could be made aware of rough estimates or time remaining in the GUI.
19	User-Friendliness	-	Navigation pane (on the left) is missing top-level headings; need to update router/index.js file.
20	User-Friendliness	-	Gantt charts could be made to look more professional.
21	User-Friendliness	-	On the final results page, after the calculations have been performed the "view results" button is temperamental and sometimes needs to be clicked 3-4 times.
22	User-Friendliness	-	Some explanation of what the terminology means on the GUI would be useful e.g. explanation of what complexity levels mean.
23	User-Friendliness	-	Some buttons should be relabelled to reflect their meaning better. For example, in Projects > Enter Study Details > 'Validate' should be changed to 'Update'.
24	User-Friendliness	-	Some more descriptions of what parameters mean on the GUI would be useful (information buttons have since been added which are very helpful).
25	Performance and Accuracy	-	Export results to json" isn't working – assume this will be fixed for the Beta version.
26	Performance and Accuracy	Other module inputs	When saving the uploaded module inputs, the button "Create" should be changed to "Save".
27	Performance and Accuracy	Other module inputs	Perhaps the "Create" (or "save" as mentioned above) button should be disabled until all five module inputs are provided – if that's the case.
28	Performance and Accuracy	Other module inputs	The process of inputting data is easy and intuitive.
29	Performance and Accuracy	LMO studies page	As a result of being in Standalone mode – you have to delete the files then reupload and can't make edits to the files. Being able to edit other module inputs would be beneficial but not essential.
30	Performance and Accuracy	LMO studies page	We're not sure why site inputs are separate to the rest of the modules.

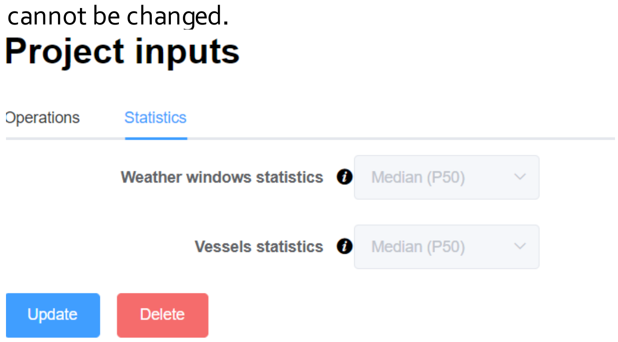
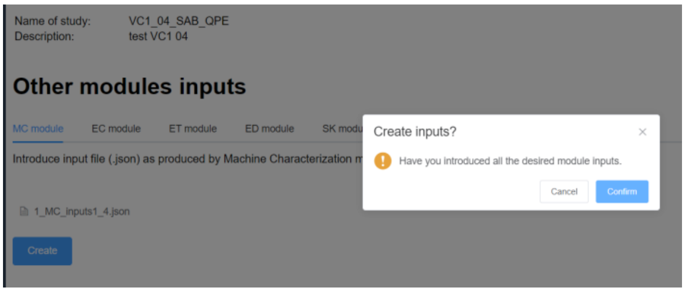
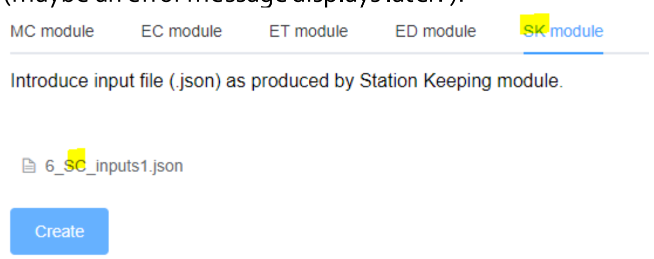
ID	Feature	Subject	Comments
31	Performance and Accuracy	LMO studies page	The "Save and Lock" functionality, plus the warning that results downstream will be lost, is excellent. However, once the results have been run, you can't go back and check what you ran (the only option is to delete and start again). We wanted to check if we had selected median for the weather windows and vessel selection but couldn't. A solution could be reprinting the inputs on the results page.
32	Performance and Accuracy	General inputs	Great that the inputs are less/simpler for lower levels of complexity.
33	Performance and Accuracy	General inputs	"Create" should be changed to "Save inputs".
34	Performance and Accuracy	Phase Requirements & Operations methods	If you open the inputs after previously submitting them, it doesn't load the previously submitted numbers e.g. When the boxes are clicked e.g. "Only select ports with MRE experience" and you navigate temporarily away from that page, when you return the boxes appear to be unchecked.
35	Performance and Accuracy	Outputs: Installation solution	Results are great and the Gantt chart is a nice feature.
36	Performance and Accuracy	Outputs: Installation solution	Units missing for almost all the results.
37	Performance and Accuracy	Outputs: Installation solution	The last 3 columns in the table are unclear – referring to the catalogue but not decipherable for the user.
38	Performance and Accuracy	Outputs: Installation solution	Formatting numbers with commas would be useful.
39	Performance and Accuracy	Outputs: Installation solution	On the Gantt chart – the last column heading is hidden (Duration (days)).
40	Performance and Accuracy	Outputs: Installation solution	The dark blue for waiting times is hard to see – suggest more contrasting colours like red and blue.
41	Performance and Accuracy	Outputs: Decommissioning solution	Decommissioning wasn't available when we ran this verification.
42	Value	-	There is no comparison feature.
43	Value	-	As mentioned previously, no indication of run time for longer calculations is currently in place.
44	General remarks	-	We were impressed with the LMO functionality
45	Usability	-	Maybe stating more clearly if ticking the boxes means 'true' or 'false' (though it seems quite obvious), maybe displaying "Repairing device at work will be considered" 

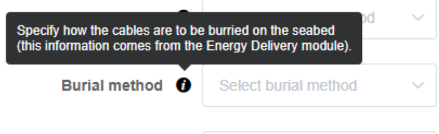
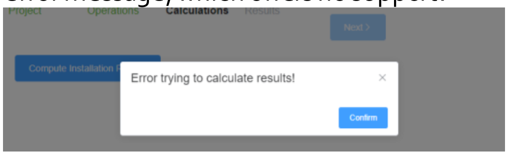
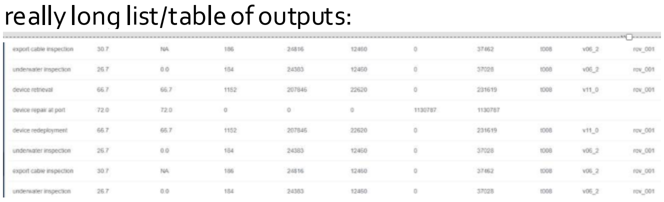
ID	Feature	Subject	Comments
46	Usability	-	Once data from other modules are provided, I suggest to allow the user to update data from the main page (as the only action allowed is to delete): 
47	Usability	-	The maintenance results were not available.
48	User-Friendliness	-	With the VC1_04, clicking on the Create button below leads to the main page, which is really confusing:  As the statement "Input to calculate vessel fuel consumption" is at the bottom of the page, we are expecting other inputs to be provided related to fuel consumption. What I understand is that the previously provided data (installation start date to project life) will be used to calculate vessel fuel consumption, and clicking on the Create button saves these inputs, but if this is the case, I suggest it to be moved ("Input to calculate vessel fuel consumption" at the top of the page for example). Or maybe this is only useful for levels 2 and 3, thus this text should be removed when complexity level 1 is used. In a general manner, using the word "Create" is really confusing, maybe "validate" or "save inputs" would be better.
49	User-Friendliness	-	There is no possibility to update data for this section, and the SC module inputs:  I suggest to add a "Go Back" button if I want to come back to the main page, and I don't want to provide a SC input file 

<table>
<tr><th>ID</th><th>Feature</th><th>Subject</th><th>Comments</th></tr>
<tr><td>50</td><td>User-Friendliness</td><td>-</td><td>There is this issue when not using fullscreen mode:


The left hand panel was not working (nothing displaying after I clicked on the dropdown cursor), and while doing a study, there was no study displaying in the Existing studies section.

</td></tr>
<tr><td>51</td><td>User-Friendliness</td><td>-</td><td>It took a while after I provided all the input files from the others modules, and clicked on “Create” to have confirmation that something happened, at least that clicking worked (I actually never waited long enough to have a message, I left and created another study with the same name, and I could access the main page with inputs from module apparently kept in memory)
The same issue occurs when clicking on the “Delete” button for “Other modules inputs”, and when adding SC data (I was normally redirected to the main page as expected after a minute):


When clicking too fast on the Save and lock button after clicking on the “Installation”button, the “Generate” button never displays in the next page:

</td></tr>
<tr><td>52</td><td>User-Friendliness</td><td>-</td><td>In complexity level 1, it is easy to forget to look at the statistics panel in project inputs. Maybe having a tracker of what panel has been seen by the user and displaying a message for what he did and what he may have missed could be useful.</td></tr>
</table>

ID	Feature	Subject	Comments
53	User-Friendliness	-	Explaining why the inputs are shaded in the statistics panel for complexity 1 could be interesting.
54	User-Friendliness	-	The json format is really hard to use for a newcomer. Thus, in case the user uses LMO in standalone mode, it is impossible to assess if data is correctly provided, with the proper format, if anything is lacking, etc…
55	User-Friendliness	-	Using a help panel to tell the user what calculations will be done would be great.
56	User-Friendliness	-	It should be explained to the user why the following values cannot be changed. 
57	User-Friendliness	-	This window is a good idea, but except the name of the file, we have no clue to say if all the inputs we want to provide have been provided. Maybe displaying the status (data provided, or not provided in the json file) for the various forms of inputs for each module, any time a json file is provided, would be helpful to judge. Actually, I did not know that clicking on “create” once was affecting all the tabs from “MC module” to “SK module”, so indeed, I was only providing data from MC module. 
58	User-Friendliness	-	Providing an input file with the wrong format seems possible (maybe an error message displays later?): 

ID	Feature	Subject	Comments
59	User-Friendliness	-	For the cables load-out method, "None" is not an option, maybe it corresponds to the default lift-away method?
60	User-Friendliness	-	I cannot understand why we should enter a value if this could be included in the json file for ED here: 
61	User-Friendliness	-	OCT/HDD methods could be further described to the user.
62	User-Friendliness	-	Maybe pointing to the relevant section instead of this general error message, which offers no support: 
63	User-Friendliness	-	In the project inputs, Operations tab, I suggest you precise maximum significant wave height, and what it refers to (is this the maximum height for towing, for installation?).
64	User-Friendliness	-	I suggest to add some precision on the exact meaning of the Safety factor for vessel selection (it seems to be applicable to the vessel deck area, but what are all the parameters that will be affected by this factor? A reference can be made to documentation).
65	User-Friendliness	-	I suggest to add precision on the "past experience in MRE" flag, and how this will be used in proposing infrastructures (maybe sorting by relevant experience for the required operations/type of technology?). This may just add weight in favour of a port terminal, instead of a strict selection criterion, as I think it is hard to find a real value added by a previous experience.
66	User-Friendliness	-	The meaning of "vessel statistics" is really unclear (and I could not find elements on the documentation D5.7 about it). Even if the weather window associated probability is more easy to understand (Figure 2.9 from D5.7), some more precision should be added.
67	User-Friendliness	-	Maybe folding useless months could help the user in visualizing the planning: 
68	User-Friendliness	-	Maybe splitting in various dropdown menus to avoid a single really long list/table of outputs: 

69	Value	-	Some of the following comments may represent major changes, but it can be a real limit to the feasibility of operations proposed by the DTOceanPlus software (e.g. if the vessel proposed is too small) - Coworkers involved in marine operations highlighted the high variability of the various tasks to be led on- and offshore, and their sequence, which are really technology dependant. They suggested to allow the user to specify its own sequence for marine tasks, with duration and impact on the number of vessels, where the vessels should be located, what can be done simultaneously etc… to account for this high variability; - Only using the device and foundations dimensions could be further improved including tidal range at the port terminal, the quayside height, the height of the device increased with the potential auxiliary manutention systems (e.g. LARS shown later), and the height below the cranes (onboard or on the quayside), as these crucial parameters should be combined to have a real candidate for the infrastructure pre-selection. The selection should be tested for the whole tidal range, along with all the heights mentioned previously, as missing one item could lead to an unfeasible combination (e.g. for a vessel we used, only high tide allowed manutention to occur, with less that a 2m vertical margin); - Vessels may need to operate in high currents, and stop some operations when currents are above limitations, even with DP vessels for tidal scenarios. We don't know if this criterion is already taken into account (it seems it is the case in the OLC), as well as usual speed limits for ROV and divers activity; - In case sediments are an issue and cameras cannot be used to support operations due to the reduced visibility (e.g. Bay of Fundy), acoustic systems can be deployed (in addition to/instead of divers and ROVs); - We don't use buried cables, cables are just laid on the ground with cast iron ballasts or rock bags along it. This option could be implemented (to account for the space and duration of manually setting ballasts along the cable); - We use a Launch And Recovery System (LARS) to install its devices. The space for the storage of the LARS on the deck and on the quayside should be accounted for (i.e. not only accounting for the device dimensions, with its subsystems), as well as some extra space for systems handling/maintenance (which could be expressed as a multiplying factor of the various drafts, maybe 5 to 10 x device drafts?). - When planning operations on the removable part of the device, we leave the support structure underwater. Thus, the dimension of this structure with the device should be provided to the software at some point. At least three sets of dimensions are thus needed: turbine on its support structure, for the first time it is immerged and decommissioned, turbine on the white structure for maintenance operation, and dimensions for all the other auxiliary system (LARS for example, cables, etc…). These sets of dimensions could be asked to the user for each phase (and eventually distinguished depending on what is to be

ID	Feature	Subject	Comments
			maintained during O&M operations), making it more adapted to user needs. - We would appreciate to distinguish maintenance operation which requires only visual inspection to those requiring to remove the device (maybe it is already included), and to display this in the outputs.
70	Value	-	Anytime a json file is provided, the duration of uploading it to the database is large, and the remaining time to complete upload could be shown to the user.
71	Value	-	We would find interesting to have the detail of how downtime is split between weather window-related downtime, repair operation, etc…
72	Value	-	We would appreciate to see for each maintenance operation if it is preventive, corrective, the durations, etc… and instead of a single number for vessel costs, we would like to be able to see the fuel cost and the vessel rental costs. I could not access the results, so maybe it is already implemented.
73	Value	-	Maybe it could be possible to add in outputs a risk indicator, related to how close we are to operational limits of the vessels, for a particular operation?
74	Usability	-	The computation time was long for VS1_VC1.
75	Usability	-	Globally, the software is intuitive, and the training sessions were useful to understand how to use the software.
76	User-Friendliness	-	The main point to be improved to my mind is the interface: the software is really good, but the interface doesn't really look professional.
77	Usability	-	With level of complexity 3 I have not been able to obtain results.
78	Usability	-	With complexity level 1 the speed is good.

CONTACT DETAILS

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EDF terminated its participation on 31st January 2019.

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