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

Deliverable D7.7

Demonstration results of integrated design tools for Wave Energy

Lead Beneficiary	EGP
Delivery Date	07/10/2021
Dissemination Level	Public
Status	Released
Version	1.1
Keywords	Wave energy, Structured Innovation, Stage Gate, Deployment & Assessment tools, real use cases, demonstration scenarios, open-source software, installation, validation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 785921

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Document Information

Grant Agreement Number	785921
Project Acronym	DTOceanPlus
Work Package	WP 7
Related Task(s)	T7.4
Deliverable	D7.7
Title	Demonstration results of integrated design tools for Wave Energy
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File Name	DTOceanPlus_D7.7_Validation of Wave Scenario_draft_04

Revision History

Revision	Date	Description	Reviewer
0.0	6-Apr-2021	Outline of structure	M.Lotta
0.1	15-July-2021	Description of use cases: objectives, storytelling input data	T7.4 partners
0.2	31-Jul-2021	Evaluation form final version	J. Henderson, I.Tunga, Maria I. Marques
0.3	20-Aug-2021	Collecting installation and operation feedback from the user	T7.4
0.4	25-Aug-2021	D7.7 & D7.8 structure alignment	M.Lotta, D.Noble
0.5	30-Aug-2021	Use case results and industrial partner assessment on the modules and the overall software	T7.4 partners
1.0	15-Sep-2021	Released version for the EC	EC
1.1	07-Oct-2021	Address EC review comments	EC

EXECUTIVE SUMMARY

This document, "D7.7 Demonstration results of integrated design tools for Wave Energy", is a deliverable of the DTOceanPlus project funded by the European Union's H2020 Programme under Grant Agreement №785921.

The objective of Task 7.4 was to carry out at least three wave energy demonstration cases to showcase the applicability of the tools to concept generation and selection, technology development and farm deployment and optimisation. Where possible, demonstration cases with strong links across the tools were selected, and priority was given to real cases (cases at highest TRL) where real data could be obtained.

The aim of this document is to present the activity carried out by the four industrial partners, CorPower Ocean, Enel Green Power, Wave Energy Scotland and IDOM, who validated the DTOceanPlus suite of tools against five wave energy validation scenarios.

These wave scenarios have been structured since the first phase of the project in WP2 and refined in WP7. These five validation scenarios aim to validate the three tools: the Structured Innovation, Stage Gate and Deployment & Assessment tools at different aggregation levels: array, device and sub-system.

The industrial partners solved real wave energy use cases by using the DTOceanPlus suite of tools with real input regarding their technology and the relevant deployment sites (Spain, Portugal, Chile). The objectives focused on different aspects such as: creating an innovative wave energy converter (WEC) concept, finding innovative solutions for a utility-scale device, defining an objective technology development stage and improving device performances for moving a step forward along the innovation path and finally to optimize array layout.

During the validation activity from July to the end of August, the industrial partners worked in a strong cooperative way together with academic partners and modules developers to jointly solve software's errors and improve modules functionalities and relevant interconnection.

This enhancement process led to four integrated tools software releases: from v0.9.0 (02/07/21) till V1.1.1, the optimised version that achieved the TRL6 maturity and was issued for public use on the 31st of August.

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ABBREVIATIONS AND ACRONYMS

AD	Assessment Design
CPO	CorPower Ocean
CR	Customer Requirement
DD	Deployment Design
DO	Design Objective
DoF	Degree of Freedom
Dx.x	Deliverable x.x from a task or work package
EC	Energy Capture
ED	Energy Delivery
EGP	Enel Green Power
ESA	Environmental and Social Acceptance
ET	Energy Transformation
FMEA	Failure Mode and Effects Analysis
FR	Functional Requirement
KPI	Key Performance Indicator
LCoE	Levelised Cost of Energy
LMO	Logistics and Marine Operations
MC	Machine Characterisation
MM	Main Module
MRE	Marine Renewable Energy
OE	Ocean Energy
OPT	Ocean Power Technologies
O&M	Operation and Maintenance
PaaS	Platform as a Service
PTO	Power Take-Off
QFD	Quality Function Deployment
RAMS	Reliability Availability Maintainability Survivability
RM	Reference Model
SaaS	Software as a Service
SC	Site Characterisation
SG	Stage Gate
SI	Structured Innovation
SK	Station Keeping
SLC	System Lifetime Costs
TRIZ	Theory of Inventive Problem Solving
Tx.x	Task x.x within a work package
VC	Verification Case
VS	Validation Scenario
WP	Work Package

1. INTRODUCTION

1.1 THE DTOCEANPLUS PROJECT

DTOceanPlus aims to accelerate the commercialisation of the Ocean Energy sector by developing and demonstrating an open-source suite of design tools for the selection, development, deployment and assessment of ocean energy systems (including sub-systems, energy capture devices and arrays).

At a high level, the suite of tools developed in DTOceanPlus includes:

- **Structured Innovation tool** (SI), for concept creation, selection, and design.
- **Stage Gate tool** (SG), using metrics to measure, assess and guide technology development.
- **Deployment Design tools** (DD), 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 tools** (AD), 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 given wave and tidal energy projects
- **Catalogue Module** (CM): to upload and review catalogues (e.g. LMO catalogues.)
- **Main Module** (MM): graphical interface to login with localhost credential and use the software

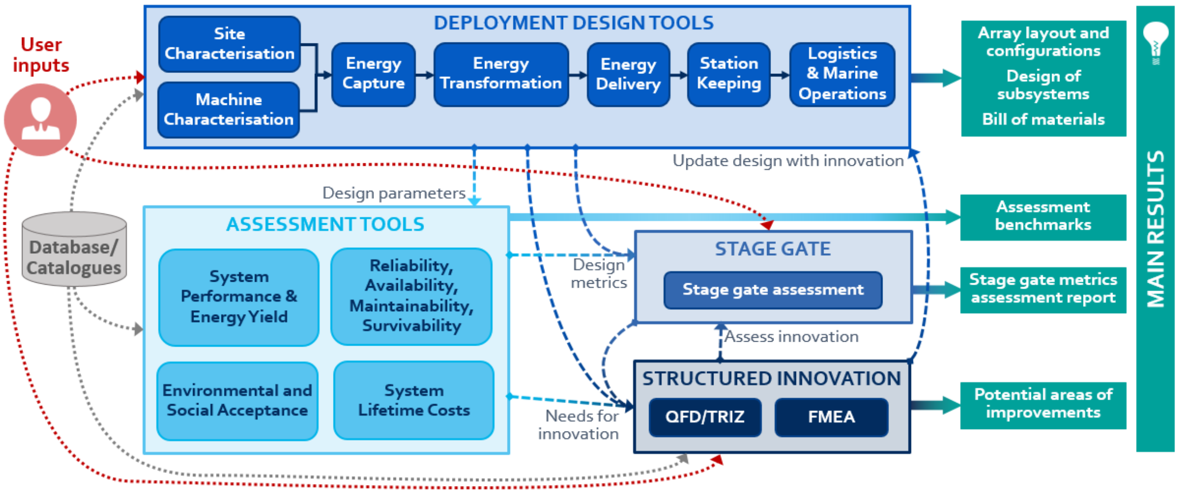


FIGURE 1.1 DTOCEANPLUS MODULES, MAIN LINKAGES AND OUTPUTS

This suite of design tools will reduce the technical and financial risks of the technology to achieve the deployment of cost-competitive wave and tidal arrays. DTOceanPlus suite will underpin a rapid reduction in the Levelised Cost of Energy (LCoE) offered by facilitating improvement in the reliability, performance and survivability of ocean energy systems and analysing the impact of design on energy yield, operations & maintenance (O&M) and the environment, thus making the sector more attractive for private investment.

These objectives and impacts are achieved by implementing nine work packages covering user engagement, tool development, demonstration of tools against real projects (thus outputting a suite of tools at TRL 6), analysis of supply chains and potential markets, exploitation, dissemination and education. Also, DTOceanPlus will produce a knowledge base with technical recommendations for the sector and deliver it through this report.

1.2 SCOPE OF REPORT

This report is the outcome of T7.4 demonstration of wave energy scenarios. Five wave energy demonstration cases have been run to showcase the applicability of the tools to concept generation and selection, technology development and farm deployment and optimisation. Cases with strong links across the tools have been selected, and priority was given to real cases (cases at highest TRL) where real data in most of the cases were obtained. A comprehensive analysis of results is presented to extract useful information on the impact potential of wave energy design decisions in terms of key metrics.

1.3 OUTLINE OF THE REPORT

The remainder of this document is structured as follows:

- **Section 1:** provides an **introduction** to the report,
- **Section 2:** summarises the **methodology**,
- **Section 3:** covers the **installation and computing device selection**,
- **Sections 4-6: document the wave energy validation scenarios (VS):**
  - VS description and objectives,
  - Tools selection and input data description,
  - Results of validation against partner's proprietary data,
- **Section 7: Summary of the demonstration activity outcomes**,
- **Section 8: Conclusions.**

2. METHODOLOGY

The principal aim of the demonstration task was for the industrial partners to evaluate the functionalities of the tools using the examples of their real projects. To achieve this, the following actions were completed:

- **Definition and refinement of the Verification Scenarios**: this has been achieved by analysing the key features of the tools and the associated User Stories accounting for levels of complexity, standalone mode, wave and tidal scenario, array layout and network topologies.
- **Collection of data**: a collection of input/output control data and project data (from catalogues and default data) have been defined and collected.
- **Organisation of training sessions, documentation, and ongoing support**: training sessions on using tools have been provided to both the technical verifiers and the industrial partners.
- **Definition of Evaluation Criteria**: a common Software Evaluation Form was developed and used to record the demonstration of every DTOceanPlus module.

2.1 DEFINITION AND REFINEMENT OF SCENARIOS

An important task within the DTOceanPlus project is to validate the novel toolset using real data. This requires a set of validation scenarios (VSs), also known as demonstration scenarios. These were developed in task 2.3 of the project and reported in D2.3 [1], then refined in task 7.2 and reported in D7.2 [2]. Six validation scenarios were developed to validate the tool at array, device, and subsystem level with both wave and tidal technologies. Within this, some VS had sub-scenarios with different industrial partners. These are summarised in Table 2.1.

While the selected Validation Scenarios do not directly cover every permutation of use-case, technology type and technology aggregation level, they do deliver validation of all the tool functionalities necessary to support those permutations, meaning that the resulting validation of the suite of tools is complete.

TABLE 2.1 SUMMARY OF VALIDATION SCENARIOS

Aggregation	Wave	Tidal
Array	**VS3: Deployment Design** Lead: IDOM Array: IDOM MARMOK A14 x 8 Site: BiMEP	**VS6: Deployment Design** Lead: Nova, Sabella, Orbital Array: NOVA M100DD x 10-50, 1,5 MW SABELLA turbines, Orbital O2 Drivetrain Scaling Sites: Bluemull; Fromveur; EMEC Berth 5
Device	**VS1: Structured Innovation** Lead: CorPower, EGP, WES Devices: CorPower C4, OPT-PB150, New concept Site: Aguçadoura:Portugal; Valparaiso: Chile; generic high – med – low energy sites	**VS5: Stage Gate** Lead: Orbital, Sabella Device: Orbital O2; SABELLA D15 Site: EMEC Berth 5; Fromveur
Subsystem	**VS2: Stage Gate** Lead: CorPower Subsystem: CorPower C4 Site: Aguçadoura:Portugal	**VS4: Structured Innovation** Lead: Orbital Subsystem: Orbital O2 Connectors Site: EMEC Berth 5

2.2 COLLECTION OF DATA

The plan for this task was to use as much real data as possible from the projects and sites of the industrial partners demonstrating the tools. Unfortunately, more reference data and example sites within the tools were needed than originally planned due to the unavailability of multi-device wave energy arrays installed at sea. Future testing of the tools may use the data identified from these tasks. However, this could be equivalent to testing at an earlier stage in project development, where this data may not readily be available.

2.2.1 CONFIDENTIAL DATA

It is agreed that the input data belonging to the partners involved in the validation task T7.4 and the output data obtained by the partners during the use of the software are all considered confidential data. For this reason, these will not be disclosed to the other partners of the project.

Partners involved in T7.4 will provide general information and public data for explaining the validation use-case, the relevant site and their wave energy technology. The results of the validation scenarios will be presented in this document: evaluation form scores where partners are requested to fill in an evaluation form assigning scores (1:strongly disagree to 5: strongly agree) to the DTOceanPlus tools functionalities and the overall suite of tools. These scores will be processed and presented, putting in evidence points of strength and improvement areas.

2.3 TRAINING SESSIONS, DOCUMENTATION, AND SUPPORT

Training sessions were held as part of the Verification tasks in WP3-6, reported in deliverables D3.3 [3], D4.3 [4], D5.8 [5], & D6.6 [6].

Technical partners were available to offer support and ongoing troubleshooting of issues arising during the demonstration tasks. This was achieved through a range of meetings, emails, video calls, and primarily Slack messaging.

2.4 DEFINITION OF EVALUATION FORM QUESTIONNAIRE

The evaluation criteria for the demonstration tasks were developed from those used in the verification tasks in WP3-6. A similar software evaluation form was used to collate and record feedback from the industrial partners.

A series of questions and statements were included, first covering the individual tool then use of the overall suite, as listed in Table 2.2. Each statement was ranked on a 5 Point Likert scale of (1) strongly disagree, (2) disagree, (3) undecided, (4) agree, and (5) strongly agree. A free-text comment was also included per statement.

TABLE 2.2 QUESTIONS/STATEMENTS IN SOFTWARE EVALUATION FORM

ID	Statement
1	**Structured Innovation Tool**
1.1	The SI tool helped find new solutions or new technology development paths to improve the relevant design.
1.2	Among the solutions achieved using the SI tool, solutions were already obtained by adopting traditional engineering methods (optimisation by trade-off solutions).
1.3	There are value-added in using SI tools methods (QFD, TRIZ and FMEA). Specify the most helpful steps for obtaining innovative results.
1.4	Specify, among the SI tool's methods, the least user-friendly steps.
1.5	The steps are clear and well structured. The information flow is smooth. The documentation and supporting material was sufficient.
1.6	Is there any critical feature missing? Indicate how much effort you spent using external software to manage DTOcean+ functionality gaps.
1.7	The results of the QFD/TRIZ and FMEA can be exported for further post-processing or reused in additional design activities/tools
2	**State Gate tool**
2.1	The SG tool helped in my decision making, e.g. Where to focus technology development activities, areas of improvement to work on, or R&D focus required
2.2	The SG tool gave me a greater understanding of where my technology is in the technology development pathway
2.3	I found the tool easy to use
2.4	The study comparison feature was useful
2.5	The Activity Checklist was straightforward to fill out
2.6	I understood the steps in using the tool as the documentation and support provided was sufficient
2.7	The SG tool helped align (or confirm alignment) of my technology development activities with funder expectations
3	**Deployment Design tools SC/ MC/ EC/ ET/ ED/ SK/ LMO**
3.1	The use of studies and entities allows comparing advantages and limitations of various design alternatives
3.2	The design steps are very clear and well structured. The information flow is smooth. Do you miss any critical design feature that is not computed?
3.3	Deployment modules are sufficiently flexible to capture my project-specific needs, technology characteristics and desired solutions. If not, please indicate which module (and why) does not meet your expectations.
3.4	Deployment modules produced results that are realistic considering the level of detail of the inputs provided. If not, please indicate which module (and why) does not meet your expectations.
3.5	Results can be exported for further post-processing or reused in additional design activities/tools
3.6	The catalogues are populated with relevant information to build credible designs.
4	**Assessment tools SPEY/ RAMS/ ESA/ SLC**
4.1	The four categories of assessments provide sufficient evaluation criteria to assess the strengths and weaknesses of my technology. If not, please identify which metric is not covered
4.2	The assessment results are clear and presented in a structured manner. They are relevant for communication with decision-makers

ID	Statement
4.3	The assessment modules produced results that are realistic considering the level of detail of the inputs provided. If not, please indicate which module (and why) does not meet your expectations.
4.4	Results can be exported for further post-processing or reused in additional activities
5	**Global suite of tools (installation & operation)**
5.1	The installation guideline is clear and easy to complete
5.2	The installation process was completed without errors
5.3	The software can be run from my local workstation without any issue
5.4	The prerequisite specifications were clear (memory, OS, processor…)
5.5	The process of inputting and formatting data is expected with the level of detail
5.6	The description/guidance is useful for learning how to use the software
5.7	I am satisfied with the overall speed of computation
5.8	The tool met my needs in the relevant stage of the project lifecycle
5.9	The modular architecture of the software provides me with the freedom to focus on the relevant design needs
5.10	The tools can handle the complex data flows efficiently for the relevant stage of the project lifecycle
6	**Integration**
6.1	I was able to use the tools in Standalone mode
6.2	I was able to use the tools in Integrated mode
6.3	The tools are flexible to use for different design objectives and iteration cycles.
6.4	Dataflow is efficient
6.5	The user has control of the design process
6.6	The tools can handle the complex data flows efficiently for the relevant stage of the project lifecycle

3. DTOCEANPLUS INSTALLATION

3.1 INSTALLATION REQUIREMENTS

DTOceanPlus can be installed on Windows 10, macOS 11, or Linux operating systems using Docker. It can be installed either on a local workstation/laptop or a company intranet server. As development software, the installation requires a relatively powerful computer. The minimum computer specification to install and run DTOceanPlus is:

- Memory (RAM): 12 GB minimum, 16 GB+ recommended
- Processors (CPUs): 2 minimum, 4+ recommended
- Disk Space: >10 GB free space
- The “Docker Desktop” open source software must be installed before installing the DTOceanPlus software, and high-level administrator rights must be owned to succeed in Docker installation. Available RAM for running Docker: 9 GB

The list of minimum computer features to install and run DTOceanPlus is presented in Table 3.1:

TABLE 3.1 HARDWARE AND SOFTWARE REQUIREMENTS FOR INSTALLATION AND RUNNING OF THE TOOLS

Computer features	CPU	2-4 processors
	RAM	12GB
	Physical memory	64 GB
Operating systems prerequisites	Microsoft Windows 10 Pro	Version 10.0.1863
	Linux 10	Architecture x86_64
	macOS	Version 11.1

3.2 COMPUTER SELECTION

The computer(s) used by the different partners in T7.4 are listed in Table 3.2.

TABLE 3.2 INDUSTRIAL PARTNERS' SOFTWARE AND HARDWARE USED FOR INSTALLATION

T7.4 partner	PC	Work-station	Server	Internet connection	Nº Processors	CPU	RAM	Operating System
CPO	HP EliteBook 830 G5			Online	4	Intel(R) Core(TM) i5-8250U 1.60GHz	8GB	Windows10 64bit
EGP		Dell Precision 7720		Offline	4	Clock: 3.1GHz	16GB	Windows10 64bit
WES	Dell Precision 5510			Online	4	Intel® Core ™ i7-6820HQ CPU @ 2.70 GHz	16GB	Windows 10 Pro
IDOM		X		Online		Intel Core I7-4720HQ CPU 2.60 GHz	16GB	Ubuntu 20.04.1 (Linux10)

EGP put in place some preliminary controls before starting the installation of the software. The Digital Hub Department in charge of the IT and OT Security of the company held some conference calls with Open Cascade (OCC) partners to learn about DTOceanPlus architecture and inform OCC about the Cyber Security policies that must be fulfilled for the installation of the DTOceanPlus on EGP IT assets.

EGP Digital Hub provided OCC with the two applicable guidelines with relevant checklists:

1. IT SECURITY GUIDELINES – APPLICATIONS
2. CLOUD SECURITY FOR SAAS AND PAAS

OCC filled in the checklist of the first guideline, but many Cyber Security requirements were not fulfilled by DTOP software.

For the time being, the second guideline is not applicable to DTOP because the software is not ready to be used as a SAAS or *PAAS.*

The DTOP weakness about cyber security requirements must be found in the software maturity that will reach TRL6 at the end of this project. IT Security improvements are already taken into account to be implemented in the next software development stage, leading DTOP to commercial maturity. This aspect is categorised as a "Technical Risk" in the "Deliverable D9.7 - Exploitation Plan".

EGP installed the DTOP on a dedicated workstation and ran the DTOP mandatorily disconnected from the internet.

3.3 DTOCEANPLUS RELEASE HISTORY

During the validation phase, several DTOceanPlus installation versions have been released (see Table 3.3). Many iterations were made to the individual modules within the suite of tools, to fix bugs identified during the demonstration and testing process, as discussed below.

TABLE 3.3 SOFTWARE VERSIONS AND RELEASED DATES DURING THE VALIDATION ACTIVITIES

Overall software installer releases	
02/07/2021	version 0.9.0
21/07/2021	version 0.9.1
29/07/2021	version 1.0.0
31/08/2021	version 1.1.1

In early July 2021, Open Cascade (OCC) launched the first integrated version of the DTOceanPlus, allowing the software validation phase to be started by the involved industrial partners relevant to Tasks T7.4 and T7.5 wave and tidal scenarios. The first installation procedure required to use is the software Cygwin. Unfortunately, the use of this additional software caused many issues to industrial partners during the installation phase of the software on local machines. To ease the DTOceanPlus installation, OCC improved the installation procedure by providing the users with an installation executable file (.exe) to be launched in a more user-friendly way, meeting user's expectations.

On the 21st of July, the new installation procedure was officially launched during a dedicated meeting. The industrial partners were able to make the first attempts to get familiar with technical and IT features necessary for:

- "Docker Desktop" installation
- DTOceanPlus installation
- Portainer use

The forty-day validation activity was a compressed work time where industrial partners, modules developers and software integrators constantly worked in the team, exchanging real-time support and updates. Industrial partners carried out the validation, trying to use as many software functionalities as possible. At the very beginning, they faced many problems related to the:

- novelty of the IT working environment;
- module debugging to be completed;
- rough integration among the modules.

Industrial partners tested the modules at different complexity levels before starting the core activity of wave energy scenarios validation. The team continuously shared problems and solutions regarding any possible issue while running the suite of tools: warnings, error messages, hanging of the modules management (docker-portainer), input data inconsistencies, lack of dataflow interconnection among the modules, unexpected results.

A continuous enhancement process of the tools was carried out, and this required a continuous revisioning activity to refine modules functionalities and enhance the software's robustness. The versioning of each module was intensive, with initial and final version numbers listed in Table 3.4.

TABLE 3.4 INDIVIDUAL MODULE VERSIONS AND RELEASED DATES DURING THE VALIDATION PHASE

Module's version development during the validation phase			
#	Module	02/07/2021	31/08/2021
1	SI	v0.0.1	v1.0.3
2	SG	v0.4.0	v1.0.0
3	SC	v0.0.1	v1.5.2
4	MC	v0.0.1	v1.0.3
5	EC	v0.0.1	v1.1.4
6	ET	v1.0.0	v1.15.5
7	ED	v0.0.1	0.1.2
8	SK	v0.0.1	v1.5.5
9	LMO	v1.0.0	v.1.3.6
10	SPEY	v1.0.0	v1.6.0
11	RAMS	v0.0.1	v1.0.1
12	SLC	v0.0.1	0.0.4
13	ESA	v0.0.1	v1.2.1
14	CM	v0.0.1	v1.0.1
15	MM	v0.0.1	v1.0.0

4. VALIDATION SCENARIO 1: WAVE/SI TOOL/DEVICE LEVEL

Validation Scenario 1 is representative of a **Wave Energy Technology**, using the **Structured Innovation tool** at Device Level. The corresponding validation partners CorPower, EGP and WES have progressively refined the scenario scope and are presented in the subsequent sections.

4.1 VS1.1 – CORPOWER

4.1.1 VS1.1 DESIGN OBJECTIVES

In the previous WPs [7], a process for identifying the needs of the industrial partners was carried out, and a shortlist of general objectives originally set out to be achieved by using the DTOceanPlus suite of tools was selected by each partner [1, 8]. CorPower Ocean (CPO) identified the following Design Objectives:

- To rapidly evaluate different system-level concepts
- To identify the most promising investment potential to reach innovation targets at the least possible cost
- To identify areas of innovation to improve within its technology
- To create a new or improving device concept

Subsequently, due to the lack of time made available to CorPower to use and validate the tools, the scope was reduced to more realistically fit the reduced timeline made available for software testing. The scope was therefore aimed at:

- Improving the Annual Energy Production (AEP) via Hull FMEA best practices in design;
- Improving the Station Keeping capability by appropriate anchor selection.

Both objectives of which were of value to CorPower ocean in their stage of product development.

4.1.2 VS1.1 USE CASES AND USER STORY

CorPower translated general objectives into real use-cases to be used as a validation scenario of the DTOceanPlus suite of tools. The Structured Innovation design tool within the DTOceanPlus suite enabled the transfer and adaptation of the Quality Function Deployment (QFD), Theory of Inventive Problem Solving (TRIZ) and Failure Modes and Effects Analysis (FMEA) modules to the CorPower Ocean Product design process.

For CorPower Ocean, the Structured Innovation design tool was used to meet the following objectives:

- Improve the Annual Energy Production (AEP) via Hull FMEA best practices in design;
- Improving the Station Keeping capability by appropriate anchor selection.

These objectives were then translated into sub-objectives at a system level in the following way:

1. Identify potential areas of improvement for the Hull Design based on tool inputs and outputs using a combination of the three methodologies

2. Improve the usability of the FMEA data in designing the Hull and Anchoring System for the WEC.
3. Improve potential ways to improve the structural efficiency (i.e. less material for same power capture) and energy capture via the Hull design and improve cost and station keeping capacity for the WEC Anchoring.

For CorPower Ocean, the Structured Innovation design tool was used to:

- Select the most efficient Anchoring Solution for the C4 WEC Deployment based on real load conditions for the CorPower Device.
- Identify engineering routes and methodologies to advance the C4 Hull Design. Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment.

The VS1.1 has been carried out by using the following tools in standalone mode according to the Table 4.1.

TABLE 4.1 DEPLOYMENT TOOLS AND COMPLEXITY LEVELS TESTED IN VS1.1

Module/tool	Complexity 1	Complexity 2	Complexity 3
Site Characterisation (SC)			
Machine Characterisation (MC)			
Energy Capture (EC)			
Energy Transformation (ET)			
Energy Delivery (ED)			
Station Keeping (SK)			✓
Logistics and Marine Operations (LMO)			✓
System Performance and Energy Yield (SPEY)			
System Lifecycle Costs (SLC)			
Environmental and Social Acceptance (ESA)			
Reliability, Availability, Maintenance, Survivability (RAMS)			
Stage Gate (SG)			
Structured Innovation (SI)	✓		

As shown in the data flow graph in Figure 4.1, the tools have been used in a "standalone mode" to solve this validation scenario VS1.1. This means that the user must input all the data to each module in order to make the module run. When the output of a module is interconnected to the input of another module, the suite of tools is said to be used in the "integrated mode".

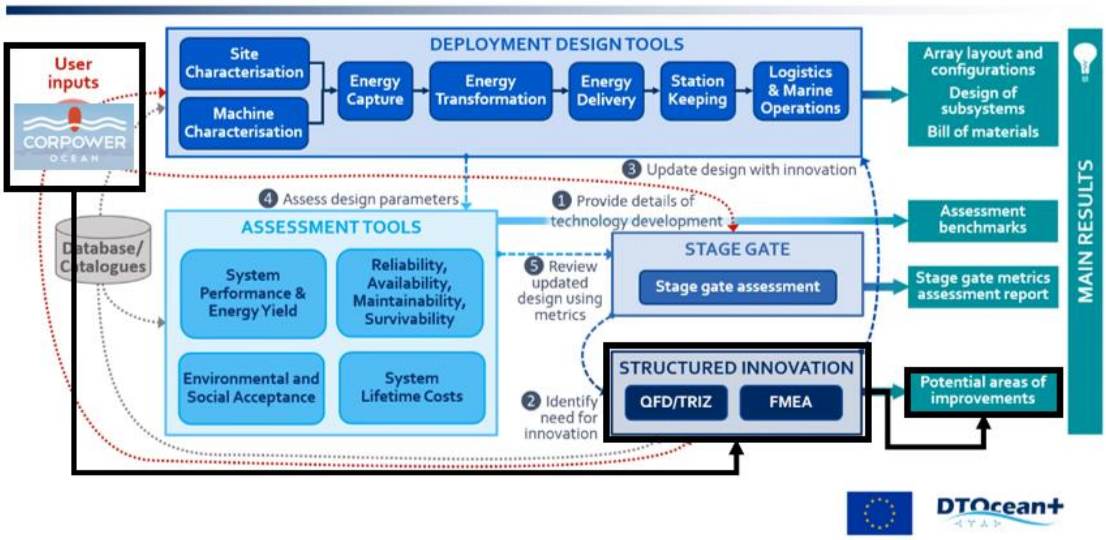


FIGURE 4.1 VS1.1 DTOCEANPLUS MODULES, MAIN LINKAGES AND OUTPUTS

4.1.3 VS1.1 INPUT DATA DESCRIPTION

4.1.3.1 SI TOOL INPUT

The actual data used as input in this scenario is not made publically available in the deliverable due to confidentiality reasons, but the inputs are described below in some detail so it can be understood what type of metrics and values were used in the analyses by CorPower.

CorPower provided the following data as input to the SI Tool TRIZ & QFD:

1. Anchor Types under consideration for the C4 device
    a. Mass Requirements
    b. Vertical Load Capacity Requirements

CorPower provided the following data as input to the SI Tool FMEA:

2. Hull FMEA real case example from CPO databases
    a. Failure Modes
    b. Design Requirements
    c. Effects of Failures
    d. Causes of Failures
    e. Control in Design

4.1.3.2 VS 1.1 – DEPLOYMENT TOOL - AGUÇADOURA SITE DESCRIPTION

Geographically, the areas with the highest wave energy levels are located on the Atlantic coast of Europe, including Portugal, one of the key countries implementing specific strategies.

The selected site to conduct the ocean demonstration is the Aguçadoura area in Portugal, at 3 nautical miles -5.5km- from the shoreline and in a water depth of 50m (Figure 4.2). The site already has a significant part of the infrastructure in place, allowing for sustainable implementation of the HiWave-5 demonstration project – first, a single C4 WEC will be deployed followed by 3 x C5 devices (improved with some learning from C4 WEC Design and Ocean Deployment) to form an array of 4 devices in total by 2023.

The Aguçadoura test site is owned by Companhia da Energia Oceânica SA (CEO), which is owned by the Portuguese Electricity Utility EDP INOVAÇÃO and WavEC, our ocean demonstration partners.

FIGURE 4.2 THE AGUÇADOURA WAVE SITE WHERE C4 AND C5 WILL BE DEMONSTRATED

In Deliverable 7.3 [8], CorPower filled in the input data checklist where the data availability and confidentiality was declared. CorPower selected the EMEC test site in Orkney's as VS1.1 and VS2 relevant site in this deliverable. However, CorPower decided to change the site to the Agucadura test site in Portugal. This choice is justified by more data available on the Portuguese site. The updated input data checklist is included in ANNEX I: VS1.1 Input Data – CPO of the present report.

4.1.3.3 VS1.1 – DEPLOYMENT TOOL – MACHINE & ARRAY GENERAL DESCRIPTION

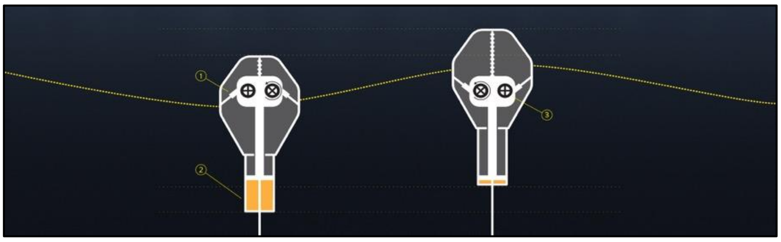
The CorPower device adopted for validation of VS1.1 is the C4 device that is herein described.

The CorPower WEC is of point absorber type, with a heaving buoy on the surface absorbing energy from ocean waves and which is connected to the seabed using a tensioned mooring line. Novel "phase control" technology makes the compact devices oscillate in resonance with the incoming waves, strongly amplifying the motion and power capture.

CorPower uses stored pressure to generate energy from waves in two directions: the upward force of a wave swell pushes the buoy WaveSprings upwards while the stored pneumatic pressure provides the restoring force driving the buoy downwards. This results in equal energy production in both directions and allows for a lightweight design with a high natural frequency.

FIGURE 4.3 CORPOWER C4 WEC

Main component description
A composite buoy, interacting with this wave motion, drives a Power Take-Off ("PTO", power train located inside the buoy) that converts the mechanical energy into electricity. The WEC consists of a light buoy connected to the seabed through a power conversion module and a tension leg mooring system. By means of a pneumatic module providing a negative spring function between the PTO and the buoy ("Wave Spring"), the CorPower WEC moves in resonance with incoming waves, making it move in and out of the water surface.



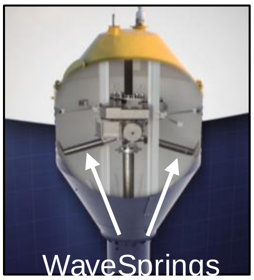


FIGURE 4.4 CORPOWER WEC WORKING PRINCIPLE & MAIN COMPONENTS

CorPower Ocean C4 Anchor Selection (SK Tool)
Following the selection of Aguçadoura in Portugal as the preferred test site, detailed design of the anchors has focused on the development of a novel anchor optimum performance for sand in terms of:

- Anchor Mass – and thereby material cost;
- Anchor Holding Capacity.

The UMACK project is developing cost-effective moorings and foundation solutions applicable to various offshore renewable energy technologies. The UMACK system will be tested in open water alongside CPO's wave energy converter next year. Therefore, CPO and UEDIN were interested in obtaining design solutions for state-of-the-art foundations (e.g. pile and gravity) to be compared with the UMACK foundation solution in terms of costs and environmental impact [9].

FIGURE 4.5 SCALED UMACK TEST ANCHOR UNDER LOAD TEST AT IWES FACILITY.

This action involved three DTOceanPlus partners: France Energies Marines (FEM), The University of Edinburgh (UEDIN) and CorPower Ocean (CPO). This work tested and validated the Station Keeping (SK) tool, developed by FEM, with CPO data. The SK tool is part of the DTOceanPlus Deployment tools, as observed in Figure 4.6.

CorPower Ocean C4 Anchor Install (LMO Tool)

The analyses were carried out for a 10 MW array of CorPower Ocean's WECs, which were assumed to be deployed in Agucadora (Portugal). The study calculated, for the deployment of 28 anchors in Agucadora, the outcomes of the installation (cost and fuel burn).

4.1.4 VS1.1 RESULTS

The results of the validation activities are presented following the sequence of the tools linkage as stated in the above Section 4.1.3

4.1.4.1 VS1.1 SI TOOL RESULTS

The results from using the SI tool were:

QFD&TRIZ – Several potential Anchoring solutions were analysed by the tool based on the requirements set by CorPower. The tool selected and then recommended the most structurally efficient design for the Anchoring for WECs = UMACK Anchor (as the use case example used by CPO).

FMEA – A detailed CorPower specific FMEA was performed for the CPO WEC Hull. The results helped to summarise the key focus areas for CorPower to use in the next design cycle.

These key results supported the original objectives:

- **Improve the Annual Energy Production (AEP);** - by enabling better design choices for the Hull and therefore reducing downtime due to Hull Failures and increased design life.
- **Improving the Station Keeping capability by appropriate anchor selection**. – by proposing the most structurally efficient anchor being developed in the market – the UMACK Anchor.

4.1.4.2 VS1.1 SK MODULE RESULTS

Figure 4.6 compiles all of the results in a graph format. Results from the DTOceanPlus SK module are presented in the blue bars. A combined validation exercise was run between UEDIN and CorPower - results from UEDIN analytical model are shown as purple dots and CorPower's as orange dots.

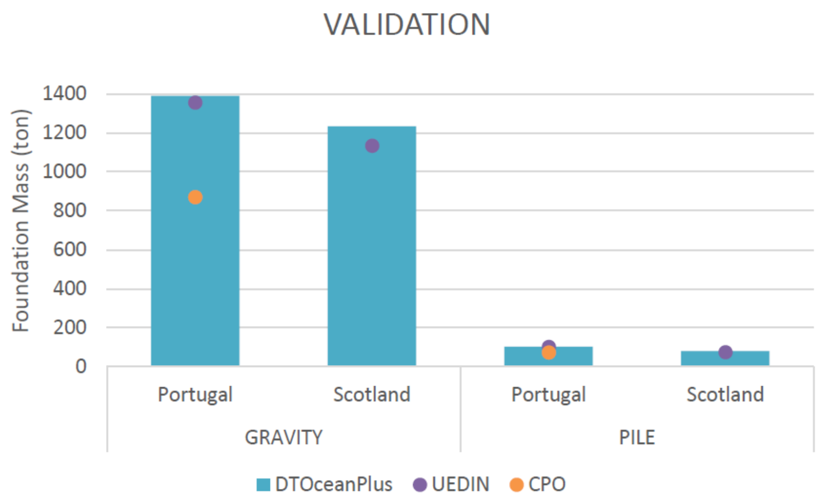


FIGURE 4.6 VALIDATION OF SK TOOL

As observed, DTOceanPlus results for both sites are aligned with the results of the UEDIN model. It is important to remember that CPO's model for gravity foundation is simplified (for example, the model does not check for sliding resistance), and, for that reason, the resulting mass is smaller than the ones resulting from the other two models. Differences in results can be explained due to differences in the models' assumptions.

Overall, the DTOceanPlus results compare very well with third-party calculations.

4.1.4.3 VS1.1 LMO MODULE RESULTS

The results from using the LMO module were:

1. DTOceanPlus provides the user with a list of vessels with valuable information, such as day rates, free deck area and vessel crane capacity. Apart from the vessels suggested by the tool, three other vessels were added to the database to represent the current fleet available to service European sites fully. For these three additional vessels, only the crane capacity and the deck areas were provided. The day rates (min and max) were calculated based on linear cost functions obtained using DTOceanPlus data

2. This validation study shows that the DTOceanPlus LMO module is a good starting point for estimating installation costs and vessel fuel burn.

3. The tool shows that the UMACK Anchor selection (as also proposed from the use of the SI Tool) produced the lowest Fuel Requirement for installation at CorPower's deployment site.

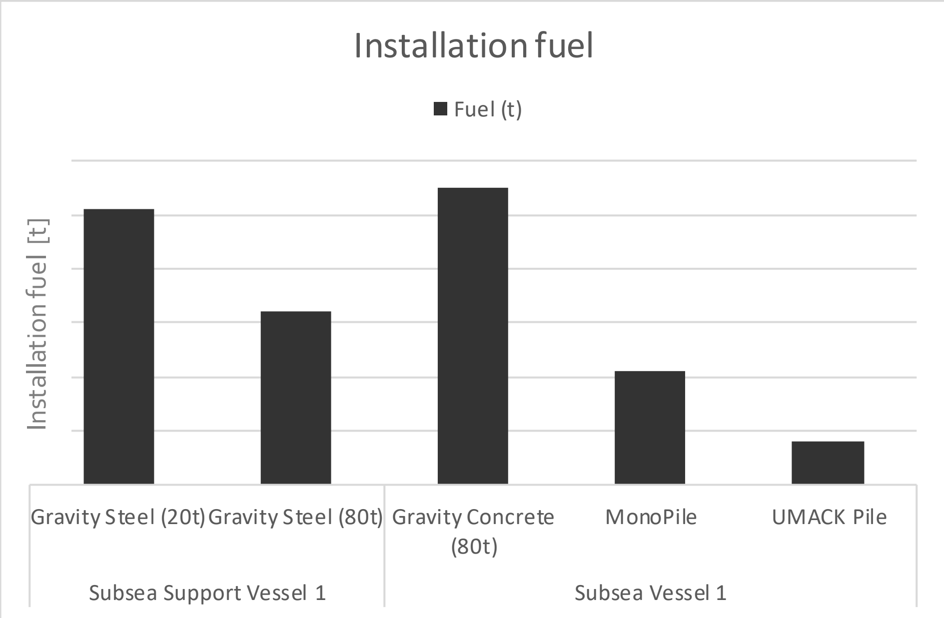


FIGURE 4.7 LMO PROPOSED ANCHOR SELECTION BASED ON SI TOOL OUTPUTS

4.1.4.4 VS1.1 OVERALL CPO FEEDBACK

In the following paragraph, feedback from CPO usage of the tools:

- **FD&TRIZ** – these functions could guide the user better overall compared to a normal design process - the QFD/TRIZ use was somehow limited due to the lack of a database of existing technologies and metrics. Therefore, these tools are only as good as the user's knowledge or exiting datasets – however, the methodology descriptions are good and put the engineering or designer in the frame of mind for such an activity. Further, the excel report generated reports the metrics well from the user criteria; in addition, the tool selects the best design choice for the Anchoring for WECs, the **UMACK Anchor** (as the use case example used by CorPower).
- **FMEA** – The FMEA methodology has been implemented in a complete and effective way. The steps are well defined and guide through the process well for those seeking to populate an FMEA. No external tools would be needed here to supplement this tool. A summary Excel report is generated well with a good FMEA table. The FMEA could be a nice tool for a risk engineer to create and track an FMEA for a component, sub-system, or device level.
  - The design steps are very clear and well structured, but the databases are limiting – meaning that the user would need to have far better Marine Operation knowledge to maximise the function of this tool.
  - DTOceanPlus provides only one value of fuel consumption per vessel. However, vessels have different fuel consumption values for different operations (e.g. mobilisation, transit, DP trials). In order to account for a more accurate fuel emission, one vessel – which the fuel consumption per operation was available – was taken as an example, and the fuel emissions were calculated. For this case, a relationship between real fuel emissions and DTOceanPlus fuel emissions was defined and applied for all the other vessels.
  - This verification study shows that the DTOceanPlus LMO module is a good starting point for estimating installation costs and vessel fuel burn. However, adjustments and refinements are necessary to attend to project needs – as each project will have different needs based on the technology requirements and site conditions.

4.2 VS1.2 – EGP

4.2.1 VS1.2 DESIGN OBJECTIVES

In the previous WPs [7], a process for identifying the needs of the industrial partners was carried out, and a shortlist of general objectives originally set out to be achieved by using the DTOceanPlus suite of tools was selected by each partner [1, 8]. Enel Green Power (EGP) identified the following Design Objectives:

- To carry out a gap analysis
- To identify enabling technologies
- To support the selection process by solving in an easier way the contradictions at the device level

4.2.2 VS1.2 USE CASES AND USER STORY

EGP built a wave energy use case that addresses the above-stated objectives. That represents an interesting real wave energy application case for using the Structured Innovation tool and the Deployment and assessment tools. The use case herein presented is the case of the wave energy converter developer Ocean Power Technologies (OPT) at the time when the company was involved in optimizing a utility-scale device, the PB150, that aimed at being competitive with other renewables. The conclusion of such work was to leave, for the time being, the power generation sector and focus on other offshore markets that found in small WECs the solution for reducing their OPEX.

The use case in the VS1.2 is to take OPT problem for a utility-scale device and adopt the SI tool to find innovative paths or suggestions that could help find new solutions for bringing WEC to a competitive level among other renewables.

Looking at the use-case proposed, the technology development carried out by OPT is based on the typical engineering optimization approach: a function object is minimised by finding a trade-off solution for solving contradictions. The same problem will be taken in VS1.2 by adopting the Structured Innovation approach to get new innovative paths that could help fill the gaps making the wave energy converter a competitive technology. The VS1.2 was carried out using the following tools:

TABLE 4.2 DEPLOYMENT TOOLS AND COMPLEXITY LEVELS TESTED IN VS1.2

Module/tool	Complexity 1	Complexity 2	Complexity 3
Site Characterisation (SC)	✓		✓
Machine Characterisation (MC)	✓		✓
Energy Capture (EC)	✓		✓
Energy Transformation (ET)	✓		✓
Energy Delivery (ED)	✓	✓	
Station Keeping (SK)	✓		Partially
Structured Innovation (SI)	✓		

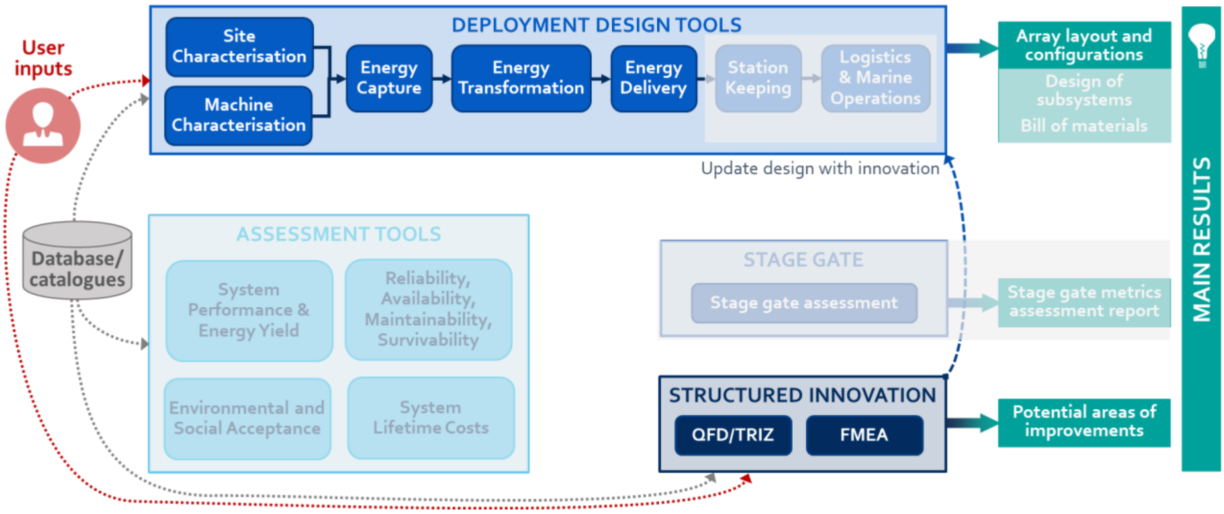


FIGURE 4.8 VS1.2 DTOCEANPLUS MODULES, MAIN LINKAGES AND OUTPUTS

The deployment tools were used in "integrated mode". This mode required the user to create a DTOceanPlus new project, input data, and run each module in the predefined order following the data path of Figure 4.8. The Site and Machine characterization modules require full input data from the user to define the deployment site and create the device model. All other modules require a smaller set of input data to be inputted by the user and receive in cascade the results of the previous module.

4.2.3 VS1.2 WAVE ENERGY PLANT DESCRIPTION

4.2.3.1 SITE DESCRIPTION

Chile has powerful and constant wave energy resources together with tidal stream and wind energies. EGP has been involved, since 2015, in the "Marine Energy Research and Innovation Centre – MERIC". For this reason, the site used for carrying out the VS1.2 is within the Chilean region of Valparaiso.

The site data used in the VS1.2 are shown in Figure 4.9. These data were taken from the "Atlas de Oleaje de Chile" realised with a Wavewatch III v.4.18 model (grid 1°x1°) of the Pacific Ocean (64 °S, 110 °E - 64 °N, 60 °W). Timeseries are generated per 22 nodes every 3-hour with a time extension of 35 years (1980-2015) [10].

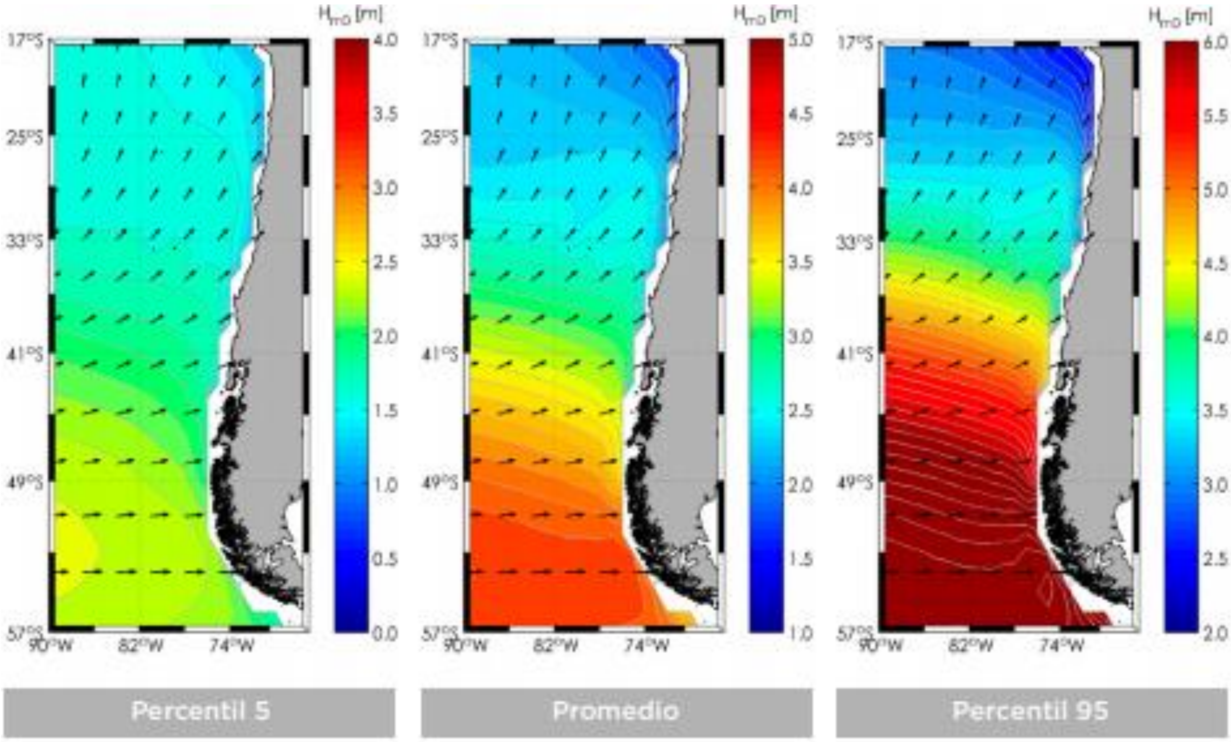


FIGURE 4.9 CHILEAN REGION OF VALPARAISO SITE DATA USED FOR CARRYING OUT THE VS1.2 [10]

Valparaiso is represented by "Node 8" (-33°,-73°) in deep water. Node 8 is characterised by the following average wave data:

- H_{mo}=2.3 m
- - T_p=13.2 s
- - T_e=10.3 s
- - D_m= D_p=226°

The Site Characterisation module has been run at "Complexity 3", which means that a full set of site data are required by the module to run.

EGP own data were imported including the:

- Lease area (.shp)
- Electric cable corridor area (.shp)

DTOceanPlus databases were used for the following data:

- Seabed type: World_SEABED-TYPE_SHOM_9km.nc
- Seabed roughness: World_SEABED-ROUGHNESS_LENGTH__SHOM_9km.nc
- Marine species: Species.nc

4.2.3.2 DEVICE DESCRIPTION

The OPT reference device is the PB150 utility-scale WEC. In VS1.2, a model similar to the PB150 was adopted, which is the "RM3" (Figure 4.10), a wave energy converter "Reference Model" designed by SANDIA - Water Power Technologies Department [11]

The RM3 takes inspiration from OPT device and reproduce the same functional principle. The RM3 is a two-body point absorber designed to convert wave energy into electricity. One body is the floater (prime mover) activated by wave motion and carries out the first energy conversion step: wave energy transformation into absorbed mechanical energy. The floater is constrained to oscillate displacing along with the spar cylinder, representing a floating platform moored to the seabed. The relative movement (mainly the heave) between the floater and the spar is transmitted to the PTO that sits inside the spar's dry environment. The PTO converts instantaneously mechanical absorbed energy into electrical energy.

Main features

- Category: Two-body point absorber Wave Energy Converter;
- Size: hight 42m, floater Width=20m , Draft = 40m;
- Rated power: 286kW
- TRL: 4
- material: steel structure;
- PTO: electro-mechanical;
- mooring & foundation: catenary moorings and drag-embedded anchor;

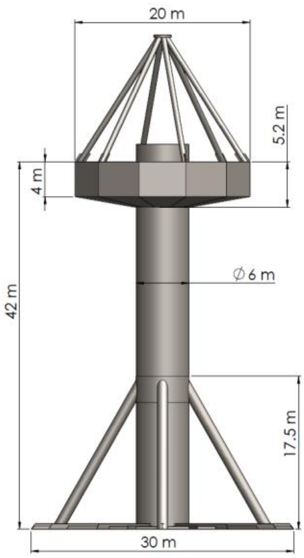


FIGURE 4.10 REFERENCE MODEL (RM3) DEVICE DESIGN AND DIMENSIONS

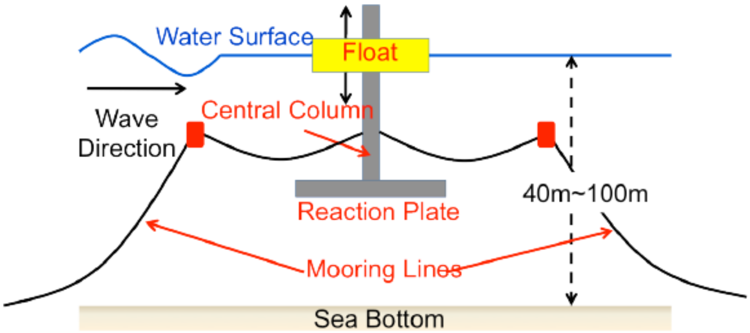


FIGURE 4.11 RM3 MOORING SYSTEM

4.2.4 VS1.2 INPUT

4.2.4.1 SI TOOL INPUT

The Structured Innovation tool, integrating the QFD, TRIZ and FMEA, was used for this validation scenario. Starting with QFD, the top-level objectives of the VS1.2 were set, customer requirements and relevant functional requirements defined, and conflicting requirements determined. TRIZ was then used to find alternative solutions to the conflicting requirements; finally, the technical risks were assessed and mitigated using Risk Priority Number thresholds set using the FMEA.

QFD Input data:

- Objective definition: to use the SI tool to find innovative solutions or pathways to innovation aiming to reduce the machinery LCOE [€/MWh].

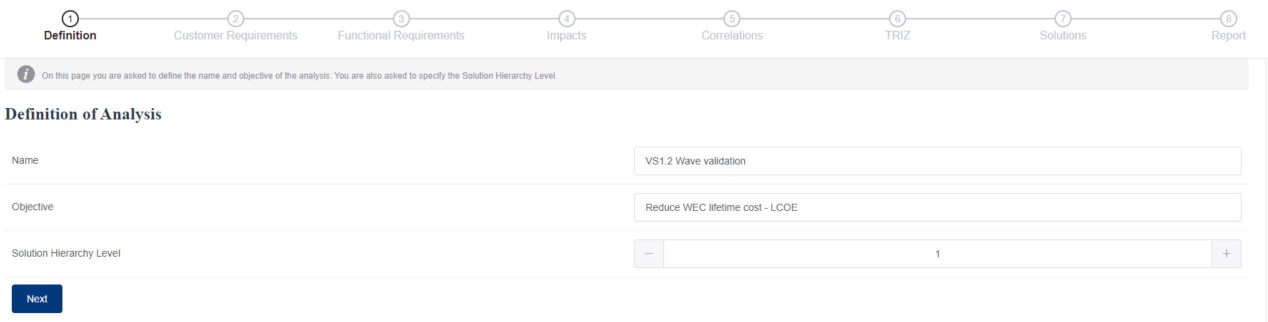


FIGURE 4.12 DEFINITION OF ANALYSIS TOP OBJECTIVE FOR VALIDATION SCENARIO 1.1

- Customer requirements and prioritisation:
  - Annual Energy Production (AEP) increase
  - CAPEX (low)
  - OPEX (low)

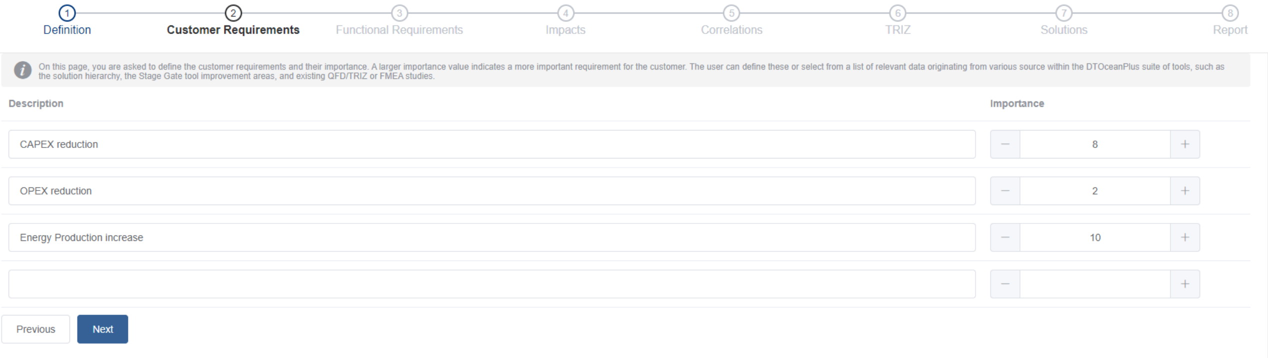


FIGURE 4.13 THE CUSTOMER REQUIREMENTS USED FOR VALIDATION SCENARIO 1.2

- Functional Requirements and targets:
  - Material cost [€]
  - Manufacturing cost [€]
  - Rated power [kW]
  - Weight [kg]
  - Capture Width Ratio [%]
  - Reliability [%]

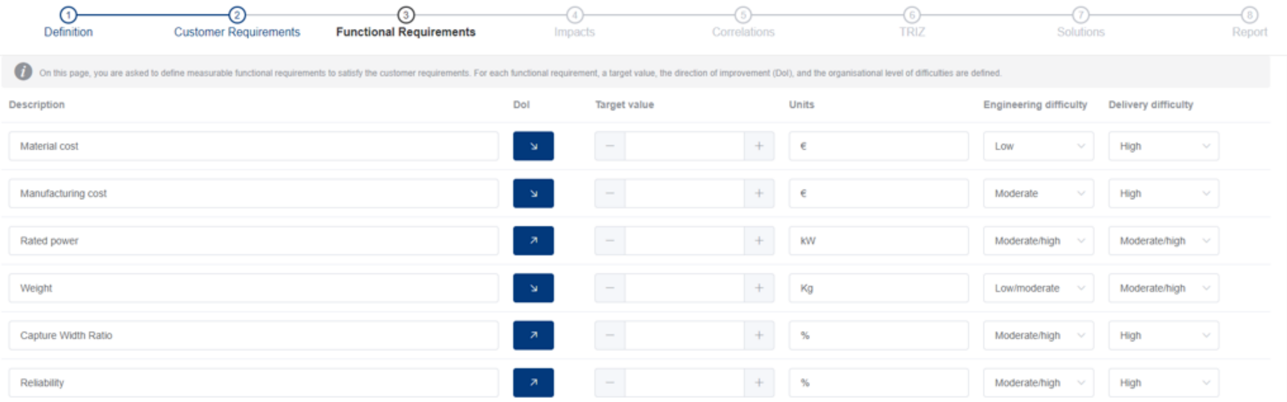


FIGURE 4.14 THE FUNCTIONAL REQUIREMENTS USED FOR VALIDATION SCENARIO 1.2

- Functional requirements impacts on Customer Requirements

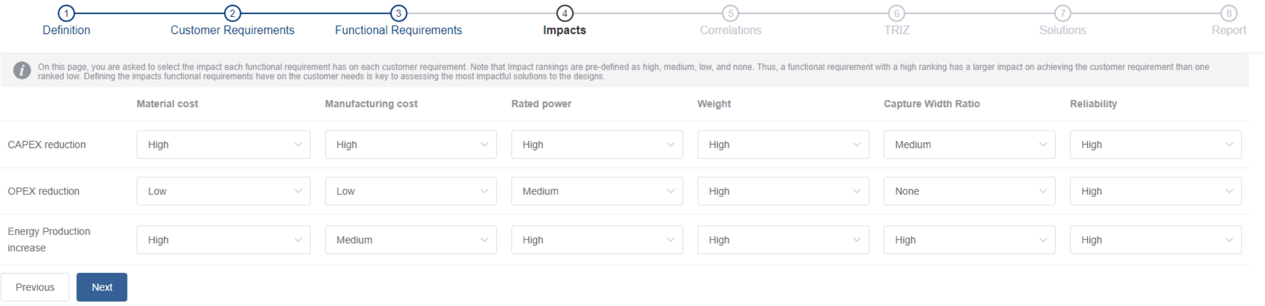


FIGURE 4.15 DEFINED IMPACTS OF FUNCTIONAL REQUIREMENTS ON CUSTOMER REQUIREMENTS

- State of the art

  Three wave energy competitor technologies, all belonging to the family of the wave activated bodies, either point absorbers and large bodies, were used to set the state-of-the-art of the technology; then the targets have been compared to the three competitor technologies and the deviations between the VS targets and competitors performance will highlight the gap to be filled with innovative measures along the development path.

TRIZ Input data

The TRIZ tool received the critical functional requirements as input data that conflict with each other.

FMEA Input data

The FMEA has been carried out on the most important FR relevant to the validation scenario.

4.2.4.2 DEPLOYMENT DESIGN TOOL: SC MODULE INPUT

The Site Characterisation module was run at "Complexity 3, which require the full set of site data to run the module.

EGP own data were imported including:

- Lease area (.shp)
- Electric cable corridor area (.shp)
- marine energy resource time series (.csv)

DTOceanPlus databases are used for the following data:

- Seabed type: World_SEABED-TYPE_SHOM_9km.nc
- Seabed roughness: World_SEABED-ROUGHNESS_LENGTH__SHOM_9km.nc
- Marine species: Species.nc

4.2.4.3 DEPLOYMENT DESIGN TOOL: MC MODULE INPUT

The Machine Characterisation module was run at "complexity 3" level. The following input data were used:

- Dimensions
- n° of wave angles: 3
- n° of wave frequencies: 20
- wave frequencies (min,max): 0.05rad/s, 1.5rad/s
- Heading angle span. 0°
- water depth: 200m
- free body Degrees of Freedom: Surge, Sway, Heave
- spar and floater modelling: mass, CoG, matrix of inertia, mesh (WAMIT models RM3_spar.GDF, RM3_Float.GDF)- joint definition: prismatic
- reference power matrix
- PTO definition per each of DoFs:
  - average damping factor;
  - average mooring stiffness

Additional damping factors and additional stiffness were not used.

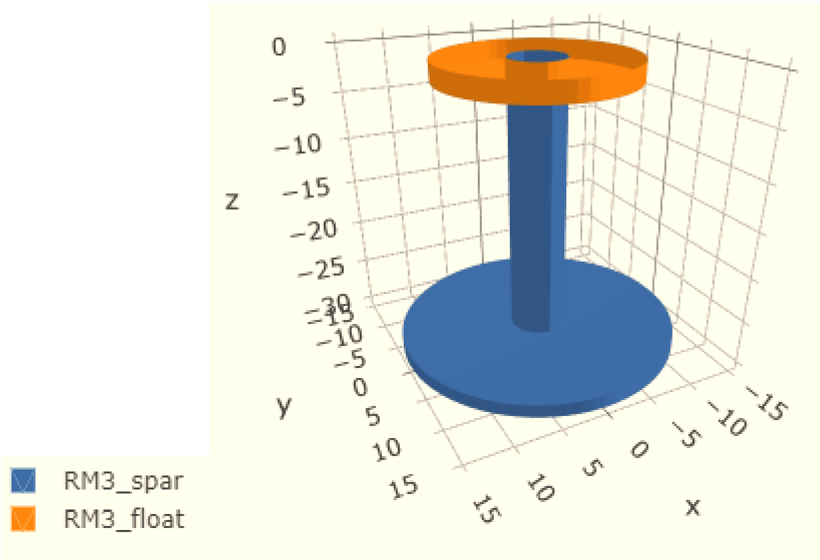


FIGURE 4.16 RM3 BOUNDARY ELEMENT MODEL MESH

4.2.4.4 DEPLOYMENT DESIGN TOOL: EC MODULE INPUT

The Energy Capture module was run at "Complexity 3". When the suite of tools runs in an integrated mode, the EC module automatically collects site data and device models from SC and MC modules previously launched.

The user must carry out the array definition by inputting directly in the module :

- number of devices

- Array layout

The array layout was set up using the two available options of the module

At first, it was specified a user-defined layout: number of devices

- Number of devices: 10
- rectangular layout

Then it was launched the same study selecting the "layout optimization method" where it was selected:

- the maximum number of devices: 10
- array geometry: staggered
- minimum device's inter distance (East, North): 10m, 10m
- optimization method: Montecarlo

4.2.4.5 DEPLOYMENT DESIGN TOOL: ET MODULE INPUT

For the ET module, the following input has been used:

- N° of parallel PTOs: 1
- Mechanical complexity level: 3
- Mechanical transformation type: Linear to the rotational system – device from Catalogue Module;
- Rated Power: 500kW

- Electrical complexity: 2
- Electrical transformation type: Permanent Magnet Synchronous Generator (PMSG)
- Rated voltage and frequency: 11kV, 50Hz

- Grid conditioning complexity level: 2
- Rated power: 500kW

- Control strategy: passive

4.2.4.6 DEPLOYMENT DESIGN TOOL: ED MODULE INPUT

The ED modules automatically receive the results of the previously launched modules: SC, MC, EC, ET.

The electrical connection specific data have been inputted manually, including:

- Cable onshore landing point: East, West coordinates
- Min/max voltage limit (p.u.)
- Onshore infrastructure cost
- Network configuration: radial with transmission collection point
- Maximum number of devices per string: 2

- Cable installation method: seabed lay
- Cable protection: cable mattress

4.2.5 VS1.2 RESULTS

The results of SI, SC, MC and EC tools are reported in the next paragraphs.

SI tool results are focused on finding inventive solutions or innovation pathways considering the set of functional requirements (FR) that will satisfy the Customer Requirements (CR) that will fulfil the main validation scenario objective, which is to fill the gap of the wave energy technology making it a competitive renewable energy technology.

To implement the critical FR into a wave energy device, the Deployment & Assessment tools were used to characterise the deployment site, model the device and array, and evaluate the FRs and the CRs of the use case.

4.2.5.1 VS1.2 SI TOOL RESULTS

<u>QFD results</u>

In the State-of-the-art, the functional requirements targets were compared to the three wave energy competitor technologies and the "potential for disruption" had been achieved:

Functional Requirement	Importance	Solutions Achieving	Solutions Missing
Weight (Kg)	180	1	2
Reliability (%)	180	2	1
Rated power (kW)	170	1	2
Material cost (€)	164	0	3
Capture Width Ratio (%)	122	1	2
Manufacturing cost (€)	114	0	3

FIGURE 4.17 POTENTIAL FOR DISRUPTION

Figure 4.17 shows the functional requirements in order of importance for this use-case scenario. The Importance score is relevant to the Customer Requirements and is evaluated by multiplying the importance of each Customer requirement by the impact that each Functional Requirement has on the Customer requirement, summing up the results along the functional requirement. The Functional requirement with the highest importance score is the most critical to meeting the customer requirement.

It is interesting to point out that apart from the material cost and manufacturing cost, solutions for the other functional requirements can already be found in this sample of the wave energy market. It must be said that a single competitor meets the solutions. This means that to have a device that meets all functional requirement targets of EGP's validation scenario, innovative solutions must be found in order to reduce the WEC LCOE. This also reflects the readiness of the wave energy sector.

TRIZ results

Each Conflicting functional requirement is translated into generic parameters using the TRIZ "39x39" contradiction matrix, from which generic solutions are identified using the TRIZ library of inventive principles. Table 4.3 presents all conflicting functional requirements and the proposed generic solutions using the TRIZ library of problem solutions.

The process is complete when the generic solutions proposed by TRIZ inventive principles are translated to solutions relevant to the initial problem. In this validation scenario, not all the inventive principles were relevant to the specific wave energy problem; however, it was interesting to notice that some solutions have already been implemented by wave technology developers using traditional engineering methods (optimization by means of trade-off). This is the case for conflicting functional requirements "material cost" and "weight", where the reduction in weight of the moving object leads to higher material strength and consequently the cost, and this can be achieved by employing composite material.

It must also be highlighted that some interesting proposed inventive principles can set the path for innovation. This is the case of highly correlated Functional requirements "capture width ratio" and "weight", which have been translated into general parameters:" use of energy by moving object" related to CWR and " weight of moving object" related to the weight. These two requirements are highly positively correlated. In fact, to efficiently absorb wave energy from mid-to-high wave energy resource sites, the prime mover must be able to be in resonance with high period waves, which requires big inertia; so if the weight of the device increases, the CWR increases too. Another interesting generic solution solving this strong positive correlation could be the "substitution of mechanical system", and a technology developer could take this path for developing a specific solution.

TABLE 4.3 PROPOSED GENERIC SOLUTIONS FOR ALL CONFLICTING FUNCTIONAL REQUIREMENTS

Material cost			
Conflicting Functional Requirement	Worsening TRIZ Class	Improving TRIZ Class	Suggested Inventive Principle
Weight	Weight of moving object	Strength	Segmentation
Weight	Weight of moving object	Strength	Counter-weight
Weight	Weight of moving object	Strength	Composite materials
Weight	Weight of moving object	Strength	Dynamism
Reliability	Reliability	Strength	Preliminary Compensation
Reliability	Reliability	Strength	Local quality
Manufacturing cost			
Conflicting Functional Requirement	Worsening TRIZ Class	Improving TRIZ Class	Suggested Inventive Principle
Rated power	Power	Ease of manufacture	Cheap disposable
Rated power	Power	Ease of manufacture	Segmentation
Rated power	Power	Ease of manufacture	Equipotential
Rated power	Power	Ease of manufacture	Intermediary
Rated power			
Conflicting Functional Requirement	Worsening TRIZ Class	Improving TRIZ Class	Suggested Inventive Principle
Manufacturing cost	Ease of manufacture	Power	Copying
Manufacturing cost	Ease of manufacture	Power	Preliminary action
Manufacturing cost	Ease of manufacture	Power	Recycling (rejecting and regenerating)
Weight			
Conflicting Functional Requirement	Worsening TRIZ Class	Improving TRIZ Class	Suggested Inventive Principle
Material cost	Strength	Weight of moving object	Substitution of Mechanical system
Material cost	Strength	Weight of moving object	Cheap disposable
Material cost	Strength	Weight of moving object	Mechanical vibration
Material cost	Strength	Weight of moving object	Composite materials
Capture Width Ratio	Use of energy by moving	Weight of moving object	Physical or chemical properties
Capture Width Ratio	Use of energy by moving	Weight of moving object	Equipotential
Capture Width Ratio	Use of energy by moving	Weight of moving object	Recycling (rejecting and regenerating)
Capture Width Ratio	Use of energy by moving	Weight of moving object	Porous materials
Capture Width Ratio			
Conflicting Functional Requirement	Worsening TRIZ Class	Improving TRIZ Class	Suggested Inventive Principle
Weight	Weight of moving object	Use of energy by moving	Equipotential
Weight	Weight of moving object	Use of energy by moving	Mechanical vibration
Weight	Weight of moving object	Use of energy by moving	Substitution of Mechanical system
Weight	Weight of moving object	Use of energy by moving	Porous materials
Reliability			
Conflicting Functional Requirement	Worsening TRIZ Class	Improving TRIZ Class	Suggested Inventive Principle
Material cost	Strength	Reliability	Preliminary Compensation
Material cost	Strength	Reliability	Substitution of Mechanical system

FMEA results

The FMEA method was quite familiar to EGP and has been used to assess some functional requirements risks. It is worth mentioning that the adoption of the inventive principle "composite material", was one of the results of the TRIZ method application for solving the conflict between "material properties weight" and "strength". The change of material from steel to composite led to a new set of failure modes analysed using the FMEA.

4.2.5.2 DEPLOYMENT DESIGN TOOL: SC MODULE RESULTS

The SC module provides statistics of marine resource time series data uploaded as an input. Results of the Site Characterisation module, shown in Figure 4.18 and Figure 4.19, match with the statistics available in Atlas de Oleaje [10].

The site characterization module has been run at Complexity level "3", and the results are needed to define the site which has been selected for a real use-case case scenario. The Site Characterization module results together with the Machine Characterization module results will be used to evaluate baseline performances of a single device RM3 in order to validate Deployment tools against Sandia experimental results and a 10xRM3 array.

SC – Site Characterisation

Variable name	Minimum	Maximum	Mean	Median	STD
Hs	0	6.5	2.29	2.2	0.7
Tp	4.76	25	13.3	14.29	2.22
Cge	0	282.61	29.54	24.43	20.18
Gamma	1	4.39	1.02	1	0.14
Spr	0	0	0	0	0

FIGURE 4.18 MARINE RESOURCE TIME SERIES OUTPUTS FROM THE SITE CHARACTERISATION MODULE

Extreme value of meteocean conditions

Variable / RP	1 year	5 years	10 years	50 years
Waves Hs [m]	4,63	5,99	6,8	7,12

FIGURE 4.19 METOCEAN OUTPUTS FROM THE SITE CHARACTERISATION

EJPD HS-DP

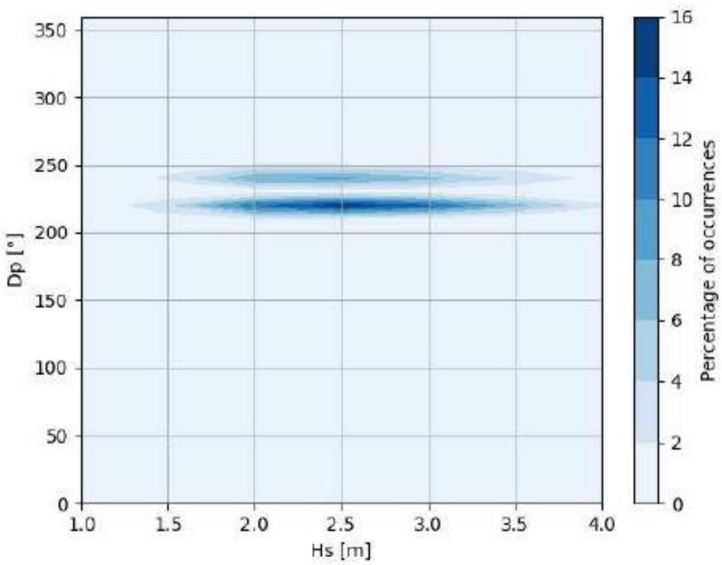


FIGURE 4.20 WAVE DIRECTION & SIGNIFICANT HEIGHT JOINT PROBABILITY DISTRIBUTION

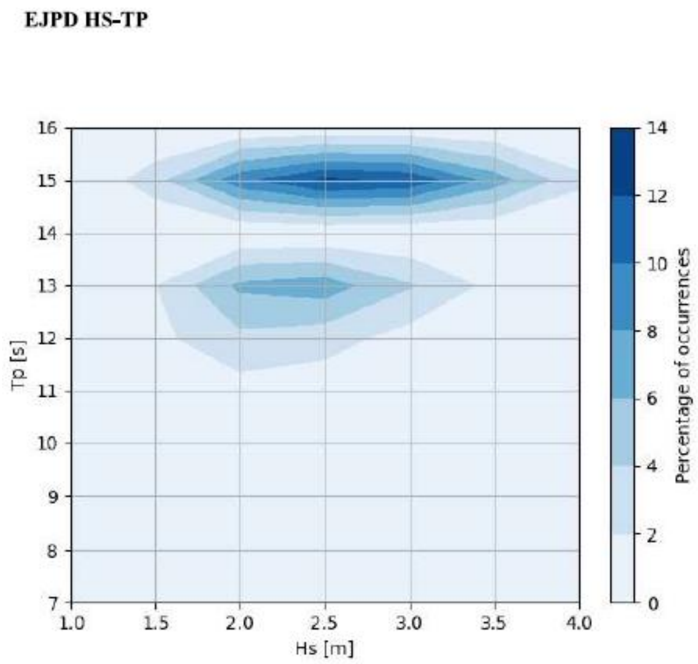


FIGURE 44.21 SITE WAVE ENERGY JOINT PROBABILITY OF OCCURRENCE DIAGRAM

4.2.5.3 DEPLOYMENT DESIGN TOOL: MC MODULE RESULTS

The Machine Characterisation (MC) module evaluates the hydrodynamic problem in the frequency domain solved by means of Boundary Element Method (BEM). The results of hydrodynamic of the two-body WEC are: the added mass, radiation damping and excitation force coefficients per three degrees of freedom of interest: surge, sway and heave. Heave motion is the main body degree of freedom for this type of device.

The added mass and damping are two coefficients proportional respectively to body acceleration and body velocity respectively and depends upon the wave period. This coefficient generates from the body motion generating waves on an initial still water surface.

The damping coefficient curve has a point of maximum extent and the relevant peak frequency reveals the value at which the WEC is most efficient in damping incoming waves. This value matches with the peak period relevant to the highest CWR.

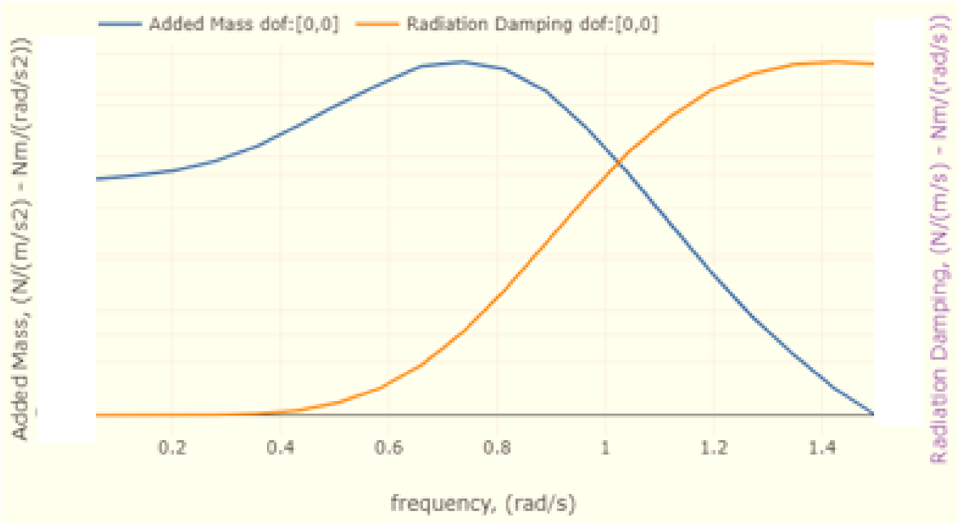


FIGURE 4.22 ADDED MASS AND RADIATION DAMPING – SURGE DOF

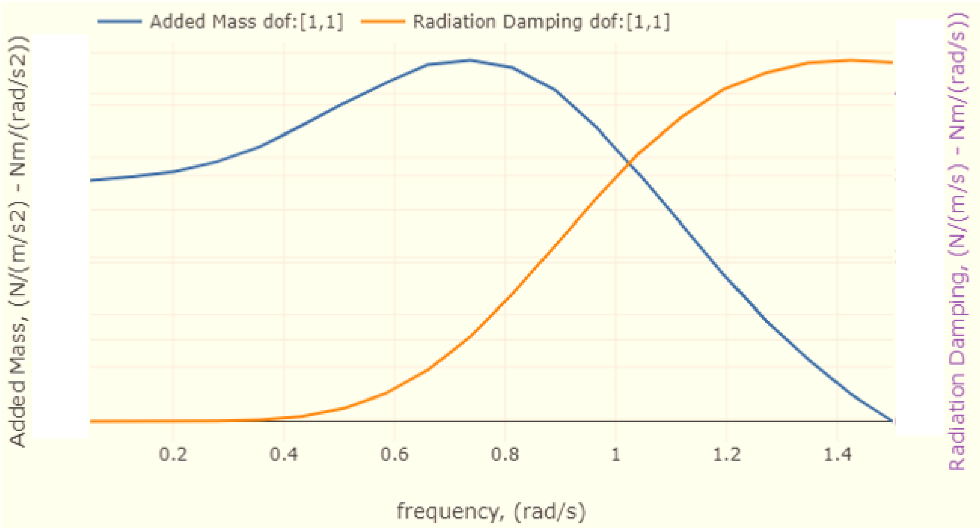


FIGURE 4.23 ADDED MASS AND RADIATION DAMPING – SWAY DOF

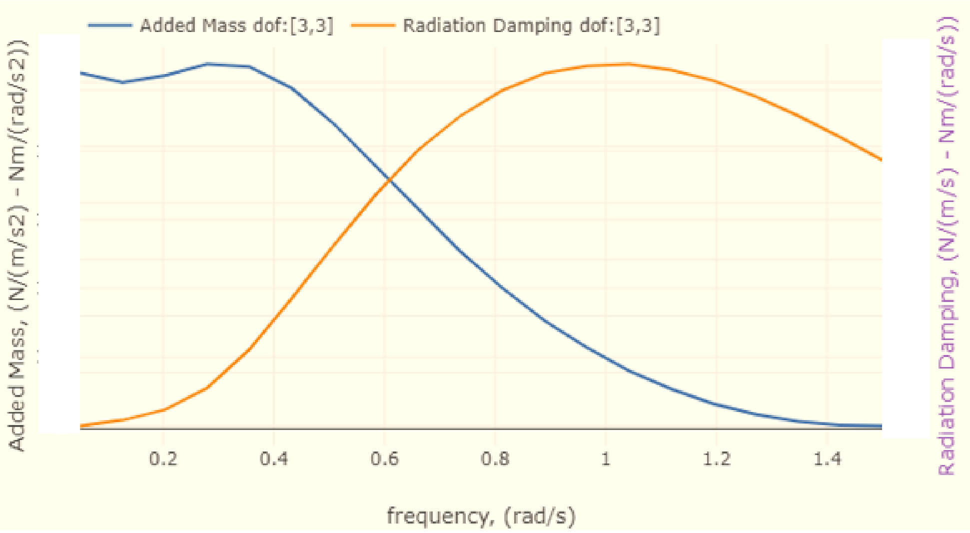


FIGURE 4.24 ADDED MASS AND RADIATION DAMPING – HEAVE DOF

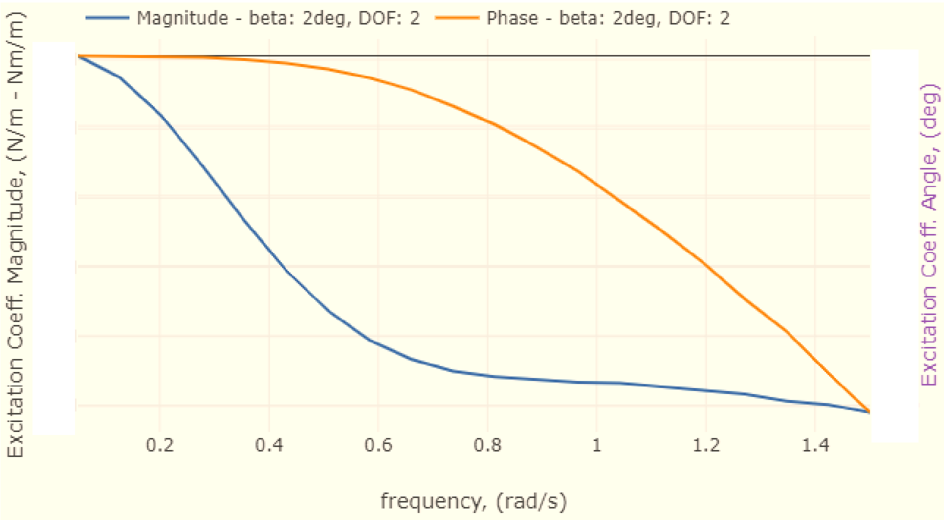


FIGURE 4.25 EXCITATION FORCE – MAGNITUDE AND PHASE

The capture width ratio matrix– CWR (%) provides the information about how much wave power is absorbed by the prime mover of the device in respect of the sea state power density and to the reference dimension of the WEC. The Figure 4.26 shows immediately the wave peak period field in which the WEC efficiently convert wave energy. The power matrix shows the mechanical power converted by the device in each sea state.

These variables are important for the VS1.2 because CWR is a functional requirement and the combination of power matrix and site scatter diagram provides the Annual Energy Production which is a VS1.2 customer requirement.

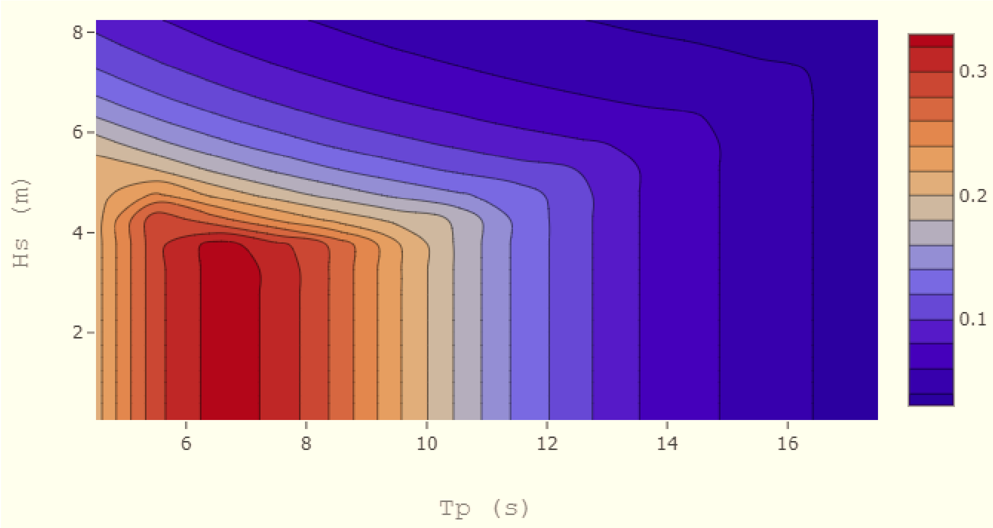


FIGURE 4.26 CAPTURE WIDTH RATIO – CWR

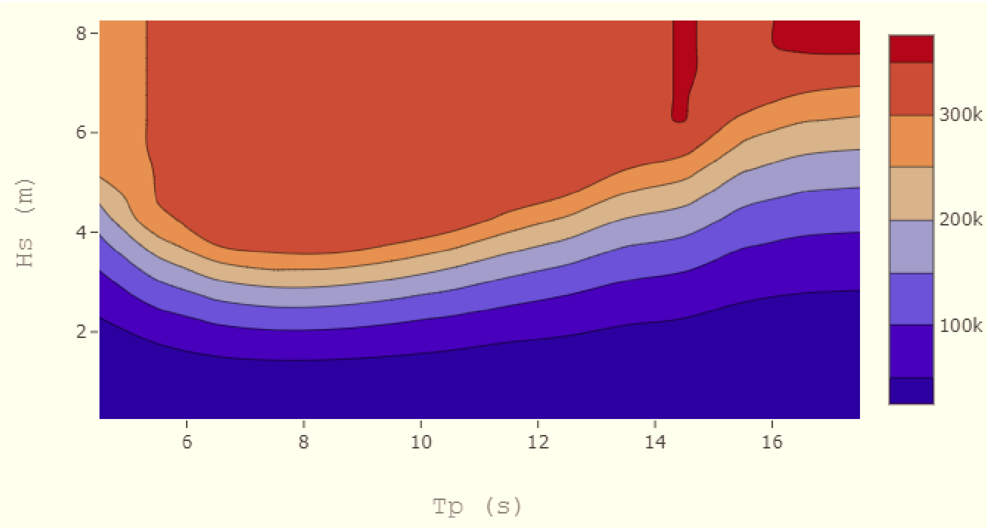


FIGURE 4.27 WEC POWER MATRIX

4.2.5.4 DEPLOYMENT DESIGN TOOL: EC MODULE RESULTS

Energy Capture module was run at complexity level 3. It fetches site data and model data automatically from the SC and MC modules.

The EC module was run to validate Design Deployment tools against RM3 results from SANDIA and set a baseline calculation.

Three cases was planned to be launched:

- 1 × WEC
- 10 x WEC Array with user defined array layout
- 10 x WEC Array: optimized layout using Monte-Carlo method

Annual energy captured by one WEC for assessing the baseline case is equal to 0,67 GWh/y see Figure 4.28

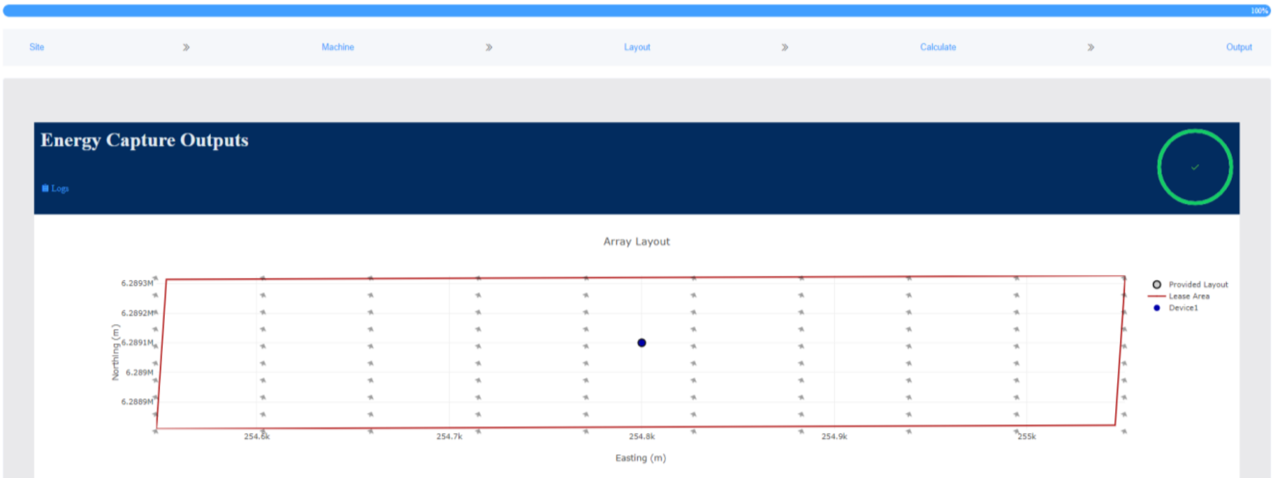


FIGURE 4.28 - SINGLE DEVICE BASELINE CASE

The energy capture by 10 x WEC array is 6,7 GWh/y, (see array layout in Figure 4.29)is approximately ten times the energy produced by one wec regardless of WEC spacing that was reduced in both East and North directions from 50m to 10m. A slight change is detected at the order of "Wh" of energy production the this confirms that the functionality which "Estimates Farm Interaction matrixes" (activated in MC module) works and that t the results don't show any effect about the very closed position of the devices resulting in a q-factor equal to one for all the devices.

The optimized layout provided same results as per user defined rectangular layout.

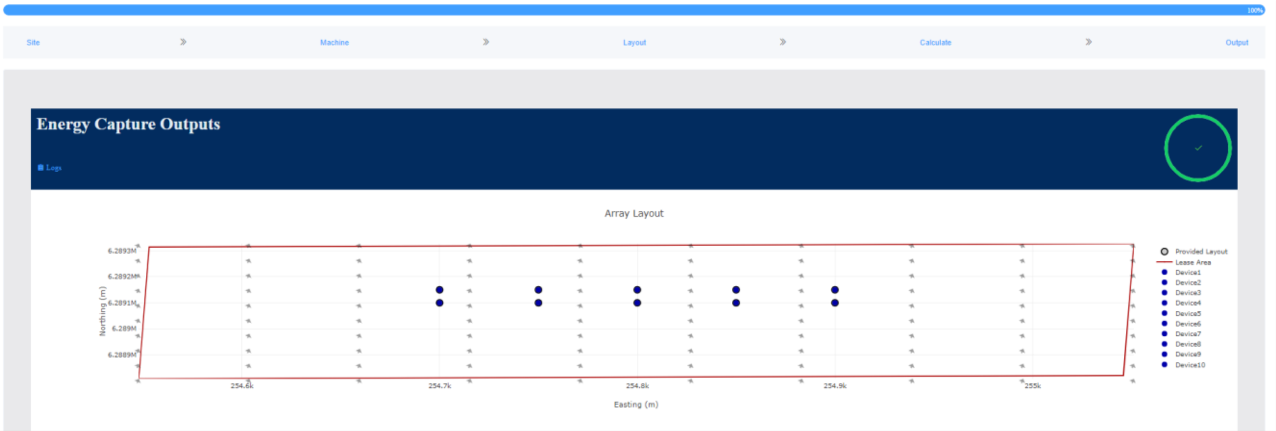


FIGURE 4.29 – 10 X WEC (RM3 ARRAY LAYOUT)

4.2.5.5 DEPLOYMENT DESIGN TOOL: ET MODULE RESULTS

The ET module results are herein shown:

WEC conversion stage	Energy [GWh/y]
Annual wave energy available	46,8
Captured from prime mover	6,7
Mechanical at PTO out	4,8
Electrical	4,5
Grid conditioned	4,4

FIGURE 4.30 10× RM3 ARRAY ANNUAL ENERGY CONVERSION

WEC conversion stage	Efficiency [%]
Prime mover (CWR)	14,3
PTO - mechanical	71,6
Electrical generator	93,8
Static converter	97,8

FIGURE 4.31 WEC ENERGY CONVERSION STAGE EFFICIENCY

The conversion efficiency values fall within the expected range of values. The evaluated CWR (14,3%)differs greatly from the RM3 model of SANDIA (29%) but this is expected because the annual energy of the device has been calculated on Chilean site which has different features in comparison to the Humbold Bay California [6]. The optimal match between the device and the site would lead to a bigger device in order to match the device best efficiency Tp with the predominant site Tp.

This will lead to higher device cost. So in order to achieve the SI tool QFD customer requirements lower CAPEX and higher AEP an innovative solution should be found to disengage the highly correlated functional requirements weight and CWR.

4.2.5.6 DEPLOYMENT DESIGN TOOL: ED MODULE RESULTS

In the following Figure 4.32, Figure 4.33 the resulting electrical grid connection layout of the 10 devices array.

This modules offer several solutions in terms of:

- devices interconnection configuration
- max number of devices per array electrical string
- n° of static cable

which could be taken into account to obtain the electrical grid connection configuration.

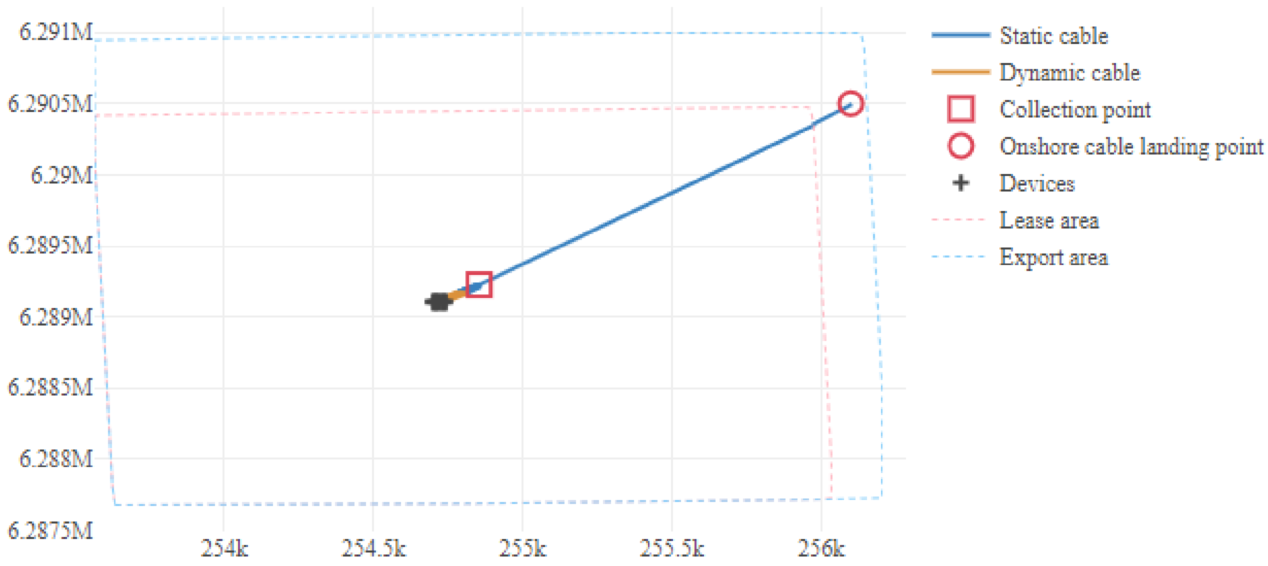


FIGURE 4.32 10 DEVICES ARRAY ELECTRICAL GRID CONNECTION

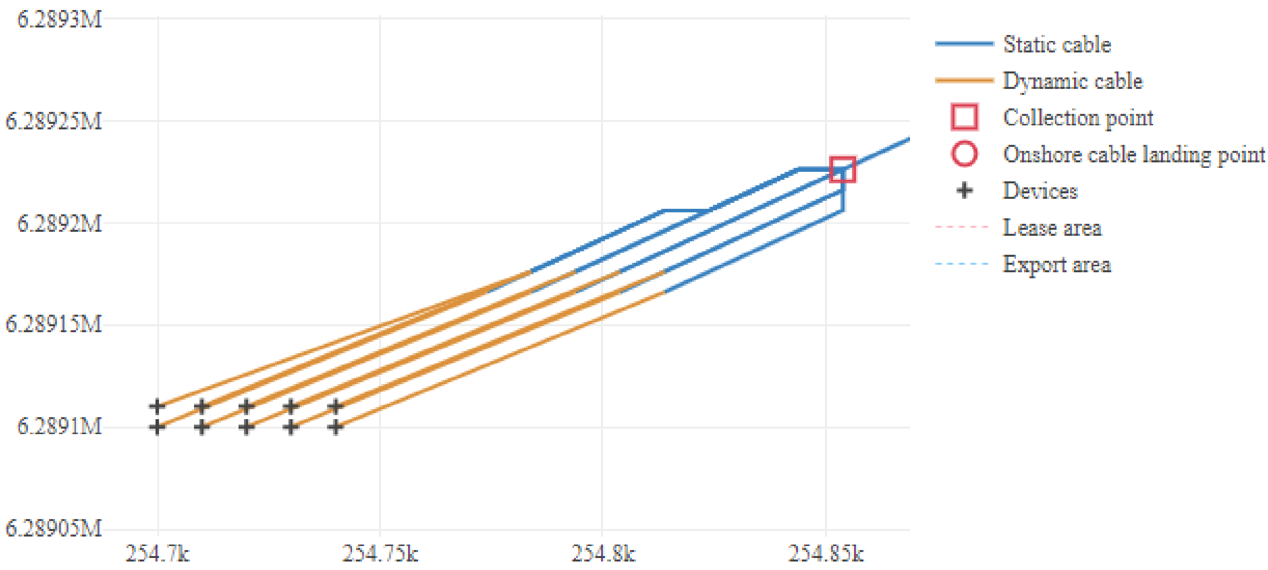


FIGURE 4.33 10 DEVICES ELECTRICAL RADIAL CONNECTION

4.2.5.7 VS1.2 OVERALL EGP FEEDBACK

The validation activity carried out by EGP demonstrated great potentiality of the software to providing innovative solution pathways to be taken by technology and project developers. The modelling features implemented in the DTOceanPlus suite of tools provides the user an effective tool to model its relevant project in terms of both site and technology to be deployed.

Enel Green Power considers a useful tool for carrying out technical, economical and environmental pre-feasibility analysis about future marine energy power plant deployment.

4.3 VS1.3 – WES

4.3.1 DESIGN OBJECTIVES

In the previous WPs [7], a process for identifying the needs of the industrial partners was carried out, and a shortlist of general objectives originally set out to be achieved by using the DTOceanPlus suite of tools was selected by each partner [1, 8]. Wave Energy Scotland (WES) identified the following Design Objectives:

- To create a new concept using the SI tool to satisfy a public funder (WES) goals of discovering attractive areas of investment for wave energy
- To identify any gaps in innovation for a new attractive concept to be commercialized.

WES scope was to generate a new wave energy concept, one single device (an array of 1), consisting of a prime mover, a PTO and other components to support the project, like moorings and foundations, electrical connections etc. The data specifications for the technology description include the key features sought in the innovative design, which are as follows:

- Wave energy device with an LCOE < 150 €/MWh
- High reliability
- Low environmental impact

TABLE 4.4 - SI TOOL FOR VS1.3

Module/tool	Complexity 1	Complexity 2	Complexity 3
Structured Innovation (SI)		✓	

4.3.2 USE CASES AND USER STORY

As a public funder, WES wants to generate a new wave energy concept that will be commercially attractive. WES wants to use a structured approach to generating this new concept and apply QFD, TRIZ and FMEA in the Structured Innovation tool to assist them in innovation. There is little to no input data since this will be a brand new idea.

Currently, WES makes use of their Scenario Creation tool as well as engages with industry and academic research to shape what future wave energy concepts may be attractive. This tool is currently being used to help WES achieve their objective of taking a structured approach to finding the winning concepts in wave energy. The SI tool can help this objective by providing an alternative approach to innovation.

The validation scenario VS1.3 has used the Structured Innovation tool directly to give an indication of a new, promising and potentially successful wave energy concept. As shown in Table 4.5 below, since the use case is about generating a brand new concept, there is very little data available.

TABLE 4.5 DESCRIPTION OF V1.3 FOR NEW WAVE ENERGY CONCEPT

Subscenario	VS 1.3
Technology Type	Wave
Aggregation Level	Device Level
Technology	New concept
Total Power	n/a
Subsystem/Component	n/a
Intended Site	Low & high energy

Data requirements

The Structured Innovation tool is tested using data specific to the intended site and related to the technology description. The data required is listed below and relates to specific functional requirements. The state-of-the-art concepts relate to existing state-of-the-art technologies or design concepts.

- Top level objectives
- Customer requirements in order of priority
- Critical functional requirements
- Impacts of functional requirements to meet customer requirements
- Interdependencies between functional requirements
- Ideal target values for each functional requirement
- State-of-the-art concept values relative to the target/ideal values for each functional requirement
- Organisational capability to design and implement each functional requirement at the ideal targets
- Potential failure modes, effects of failure, potential causes, occurrence ranking, detection measures, the Agreed threshold for action (RPN, OCC) and mitigation measures

Data sources

As the scenario's objective is to create a new wave energy concept, the user's data is assumed to be minimal, i.e. starting from a blank piece of paper. However, the three sources of data available to the user are:

- Running the Deployment & Assessment tools at their lowest level of complexity to generate the supporting design (selection of default values in respective modules)
- Using the Scenario Creation tool to provide combinations of inputs that are attractive (for Target Values) and achievable (for State of the Art).
- Literature – realistic values as necessary so that the SI tool can be run

4.3.3 VS1.3 DTOCEANPLUS TOOLS LINKAGE & DATA FLOW

The Structured Innovation tool was run in Standalone mode in this validation scenario ; since the aim was to create a new concept. All the data were user-inputted or taken from outputs of the scenario creation tool. In general, the user inputs form a large part of what is needed for the SI tool to run, including the list as described in Ch.Design Objectives4.3.1

Data such as target values and state of the art values must be known to run the tool in all cases.

Use case story telling

The scenario creation tool provided the user with combinations of commercially attractive, possible, and achievable scenarios. These were used for target values, state-of-the-art values, and to define the top level objectives. An example of the Target values used, as informed from the scenario creation tool, can be seen in Figure 4.34.

There was assumed to be no pre-existing data from the Stage Gate, Deployment or Assessment tools as in this validation scenario; the user entered the SI tool without running any of the other tools first. In other use cases of the SI tool, the user may wish to run the other tools first, and in that case the data from the other tools can help run the SI tool (Figure 4.34). Below are some of the data that can be fed into the SI tool:

- The Deployment tools can be used to generate the design of a project which could then be improved through the SI tool.
- The Assessment tools can be run to assess a project and provide the key metrics to be used in the SI tool as metrics or Target Values.
- The Stage Gate tool can be used to pass on the Improvement Areas to the SI tool, giving the user of the tool a place to start from in their improvement cycle.

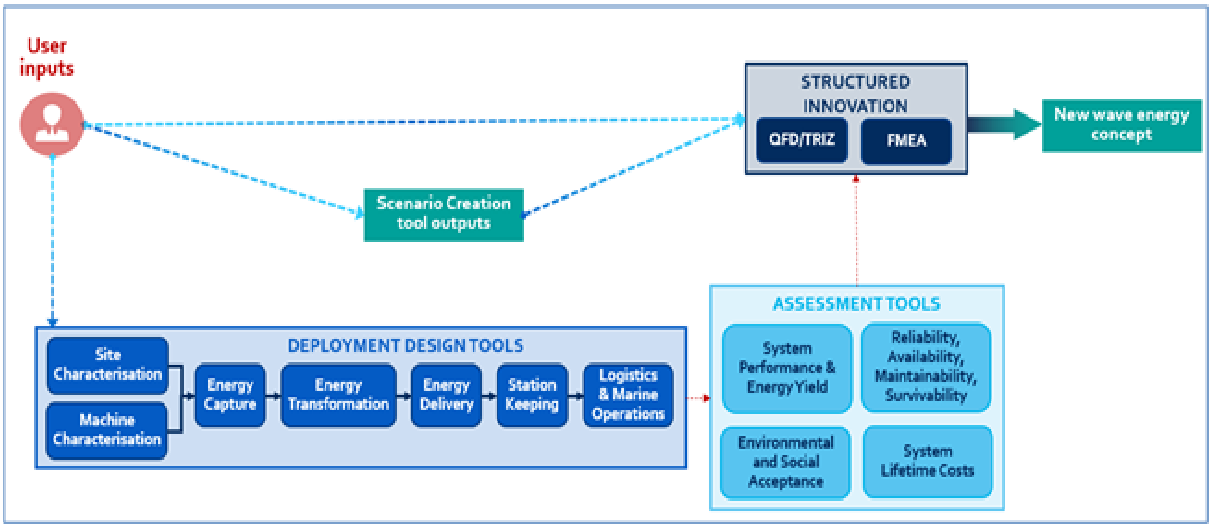


FIGURE 4.34 VS1.3 DTOCEANPLUS MODULES, MAIN LINKAGES AND OUTPUTS

4.3.4 VS1.3 INPUT DATA DESCRIPTION

4.3.4.1 VS1.3 SI TOOL INPUT

This validation scenario was for concept creation. The inputs used to align with the user story from chapter 4.3.2. The top level objectives chosen were:

- Wave device with an LCOE < 150€/MWh
- High reliability
- Low environmental impact

The functional requirements chosen are seen in the Figure 4.35 below.

1 Definition — 2 Customer Requirements — 3 **Functional Requirements** — 4 Impacts — 5 Correlations

On this page you are asked to define engineering requirements required to meet the customer requirements. The direction of improvement indicates whether an increase or decrease in the target value

Description	DoI	Target value	Units
Capital cost	↘	2200000	£
Annual Operational cost	↘	100000	£
Power conversion efficiency (wave to wire)	↗	30	%
Availability	↗	90	%
Harmful gas emissions in manufacture and operations (total for project lifetime)	↘	1000	kgCO2eq
Power generation capacity	↗	200	kW

FIGURE 4.35 THE FUNCTIONAL REQUIREMENTS USED FOR VALIDATION SCENARIO 1.3

These functional requirements were defined from Wave Energy Scotland's perspective of a public funder looking for a commercially attractive wave energy device. The values were considered to be the target values that would lead to a successful solution.

The state-of-the-art values used are seen in Figure 4.36 below.

Capital cost [£]	Annual Operational cost [£]	Power conversion efficiency (wave to wire) [%]	Availability [%]	Harmful gas emissions in manufacture and operations (total for project lifetime) [kgCO2 eq]	Power generation capacity [kW]
100000	60000	40	80	48	200
30000	70000	70	60	89	6000
400000	4999	90	70	90	40000

FIGURE 4.36 THE STATE OF THE ART VALUES FOR VALIDATION SCENARIO 1.3. THE DEVICES USED HAVE BEEN REMOVED FOR CONFIDENTIALITY.

The state-of-the-art values seen in Figure 4.36 are taken from research, and the identities of the devices are removed for confidentiality. These are real values of wave energy devices which represent the current state-of-the-art.

4.3.5 VS1.3 RESULTS

The SI tool helped WES find new technology development pathways in the sense that by directing the user of the tool to input their target values, it created transparency of the areas in technology development that should be the highest priority. The direction towards ideality helped prioritise the next steps in technology development.

In this Validation Scenario, the SI tool was run in standalone mode, which means that all inputs were input from known values or outputs of the scenario creation tool. If the SI tool was run "integrated", i.e. alongside the Deployment and Assessment tools, design data and assessed metrics could be obtained and feed into the

4.3.5.1 VS1.3 OVERALL WES FEEDBACK

SI tool to support new technology development pathways.

Although new design solutions were not found explicitly, the SI tool did guide WES in determining where to focus the R&D efforts in terms of priorities and thinking about organisational and engineering difficulties. The SI tool provided a new way of thinking about innovation and brought structure to the process.

There is great value in using the SI tool. The value added is dependent on how mature the technology is; for example, FMEA information increases as a technology matures. Knowing failure modes for a TRL 1 concept and the severity of occurrence is very difficult. The FMEA was performed in this validation scenario to assess the "potential" failure modes of the functional structure rather than the system's physical structure possible at a more mature level.

At the earliest stages, the QFD is useful, as it starts with the highest level considered 'top level objectives' and makes the user think about what they are trying to achieve, which can have a big impact on guiding the user in particular at early stages. The TRIZ tool is helpful for both early and late stage technologies. Although, the user is more likely to be able to implement big design changes at early stages than at late stages.

The SI tool does what it is intended to do and provokes innovation. It would be useful if the tool specified at the beginning the inputs which are required from the user throughout the process as it is very dependent on user inputs to get a useful output. Also, the SI tool could be iteratively used by a multi-functional team, which could be specified at the beginning.

5. VALIDATION SCENARIO 2: WAVE/SG TOOL/COMPONENT LEVEL

5.1 VS2– CORPOWER

5.1.1 VS2 DESIGN OBJECTIVES

CorPower's objectives were to perform a stage gate assessment for a PTO using the Stage Gate design tool and produce a report for the developer to demonstrate their performance.

TABLE 5.1 DEPLOYMENT TOOLS AND COMPLEXITY LEVELS TESTED IN VS2

Module/tool	Complexity 1	Complexity 2	Complexity 3
Stage Gate (SG)		✓	

Corpower aimed to understand what stage their PTO for the C4 300kW device was at, as summarised in Figure 5.1.

	VALIDATION SCENARIO 2
Sub Scenario	-
Technology Type	Wave
Tools to be Validated	Stage Gate
Aggregation Level	Subsystem Level
Lead Partner	Corpower
Other Partners Interested	EGP, WES
Technical Support Partner	WES
Technology	Corpower Ocean - C4
Total Power/Number of Devices	300 kW - 1 device
Subsystem/Component	PTO
Intended Site	Portugal - Aguçadoura

FIGURE 5.1 SUMMARY OF VALIDATION SCENARIO 2

This demonstration scenario at the sub-system level was decided to be for the Portugal – Aguçadoura site and would use real data to validate the Stage Gate design tool. In particular, CorPower was interested in financial metrics like LCOE and planned to run the Station Keeping and Logistics and Marine Operations modules to generate the designs of the moorings and foundations and understand O&M costs for the stage gate study.

5.1.2 VS2 USE CASES AND USER STORY

The use case decided after some iterative refinements was:

A technology developer, in this case, CorPower, would like to assess their PTO in the context of an array, i.e. assessing LCOE(€/kWh) to prove what stage their technology is at and highlight any areas that were unable to be assessed with a link to the Structured Innovation tool for further development.

The use case for this scenario included running the stage gate assessment as an array.

Since the scenario is to validate a sub-system, it was intended to put the PTO in the context of an array for key metrics to be calculated. CorPower suggested they start with a single device then run SG assessment in the context of an array 10MW array may be the aim but the 10MW array was not run due to lack of time.

The flow of data to the Stage Gate tool can be seen in Figure 5.2 below.

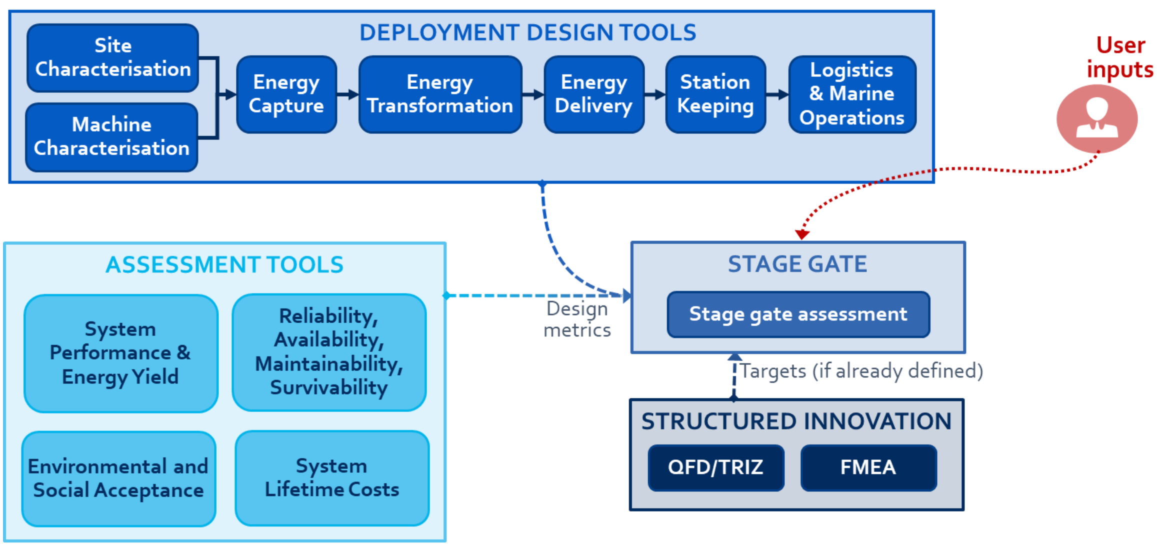


FIGURE 5.2 VS2 DTOCEANPLUS MODULES, MAIN LINKAGES AND OUTPUTS

5.1.3 VS2 INPUT DATA DESCRIPTION

The main input data used were:

- The Activity Checklist; ticking off the activities which have been complete in the technology development pathway
- The Stage Gate assessment; answering both qualitative and quantitative questions in the appropriate stage gate assessment.

This data is not displayed in this report for confidentiality.

5.1.4 VS2 RESULTS

5.1.4.1 ACTIVITY CHECKLIST RESULTS

The table below summarises the percentage of activities completed in each of the stages in the Stage Gate Framework section.

TABLE 5.2 THE OUTPUT OF THE ACTIVITY CHECKLIST FOR VALIDATION SCENARIO 2

	Stage 0	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
% activities complete	100%	100%	100%	100%	70%	3%

This is the output of the activity checklist with a statement:

"All the activities up to and including Stage 3 have been completed. This means that the technology is eligible to be assessed against Stage Gate 3-4. A breakdown of activities completed in each stage is given below. Additional information for each stage can be accessed by clicking on the relevant button."

FIGURE 5.3 A SCREENSHOT FROM THE STAGE GATE TOOL FOR VALIDATION SCENARIO 2 SHOWING THE STAGES COMPLETE

Corpower stated that t*he tool checklist works well and when completed in detail for the CPO WEC the correct Stage is identified (Stage 4). Points in the checklist are well considered and comprehensive."*

5.1.4.2 COMPLEXITY LEVELS RESULTS

Once the Activity Checklist was complete, Corpower couldn't go on to run the Deployment and Assessment tools at the correct complexity levels for their technology due to lack of time.
In table below Table 5.3 the planned use of modules and complexity.

TABLE 5.3 COMPLEXITY LEVELS RECOMMENDED FOR VALIDATION SCENARIO 2

Module	Complexity Level
Site Characterisation	2
Energy Capture	3
Energy Transformation	3
Energy Delivery	2
Station Keeping	2
Logistics and Marine Operations	2
System Performance and Energy Yield	1
System Lifetime Costs	2
RAMS	2
Environmental and Social Acceptance	2

5.1.4.3 IMPROVEMENT AREAS RESULTS

CorPower chose to use Stage Gate 4-5 as the basis of their Improvement Area study. The list of improvement areas which were identified for the Stage Gate study were identified since some activities were missing in the Activity Checklist feature since only 70% of these activities were complete. The Improvement Areas identified were:

- Controllability – with a checklist score of 17%
- Power Conversion – with a checklist score of 40%

Corpower states that improvement areas are identified well and are consistent with the stage of the CorPower Project. The Power Conversion and Control coming from the full scale PTO dry testing and the ocean deployment to come.

5.1.4.4 REPORT EXPORT RESULTS

Once the Stage Gate Assessment was complete, Corpower exported the results to a report using the Report Export functionality.

The report generated was satisfactory and deemed to be a good summary of the stage gate assessment.

FIGURE 5.4 STAGE GATE REPORT GENERATED FROM RUNNING VALIDATION SCENARIO 2

6. VALIDATION SCENARIO 3: WAVE/D&A TOOL/ARRAY LEVEL

6.1 SUMMARY OF THE VALIDATION SCENARIOS

6.2 VS3– IDOM

6.2.1 VS3 DESIGN OBJECTIVES

The preliminary objectivise proposed for this validation scenario are:

- To identify captured power trends of a cell-type array based on array configuration, distance between the devices and wave heading;
- Estimate the LCOE of selected array configurations taking into account mooring d esign, CAPEX and OPEX; and
- Check the configuration feasibility according to BiMEP restrictions (avoid rock soil, interferences with the electrical infrastructure, avoid environmental and fauna impacts, consider the bathymetry variation,…).

As shown later, during the validation activities only the deployment tools SC, MC and EC (see Table 6.1) have been employed because of time limitations (mostly due to code debugging and installation of the tools), despite IDOM´s interest in accomplishing the ambitious objectives mentioned above.

TABLE 6.1 DEPLOYMENT TOOLS AND COMPLEXITY LEVELS TESTED IN VS3

Module/tool	Complexity 1	Complexity 2	Complexity 3
Site Characterisation (SC)		✓	✓
Machine Characterisation (MC)			✓
Energy Capture (EC)			✓

Efforts have been concentrated on validating objective 1, which represent surely the first important step for a WEC farm developer and it is a required step for accomplishment of objective 2.

A brief user story is reported in the next section to address the validation scenario.

6.2.2 VS3 USE CASES AND USER STORY

IDOM is interested in a techno-economic analysis (LCOE analysis) using Deployment and Assessment tools, oriented to understand the feasibility of developing a 2MW pilot array of wave energy converters in BiMEP, implementing MARMOK-A-14 technology.

For this goal, IDOM is looking for captured power trends of a cell-type array based on array configuration, distance between the devices and wave heading, as well as CAPEX and OPEX evaluations, taking into account the mooring and umbilical design, installation, maintenance and decommissioning.

IDOM is interested in analysing a full array of devices in reference to annual energy production and costs. In order to have a full characterization of those scopes the complete DTOceanPlus should be run, but due to scheduling issues, at this stage only the energy production has been fully investigated, therefore the tools, SC, MC and EC have been opportunely selected and run (see Figure 6.1). In order to calculate in EC, inputs from SC and MC are needed in the DTOceanPlus, as shown in Figure 6.1.

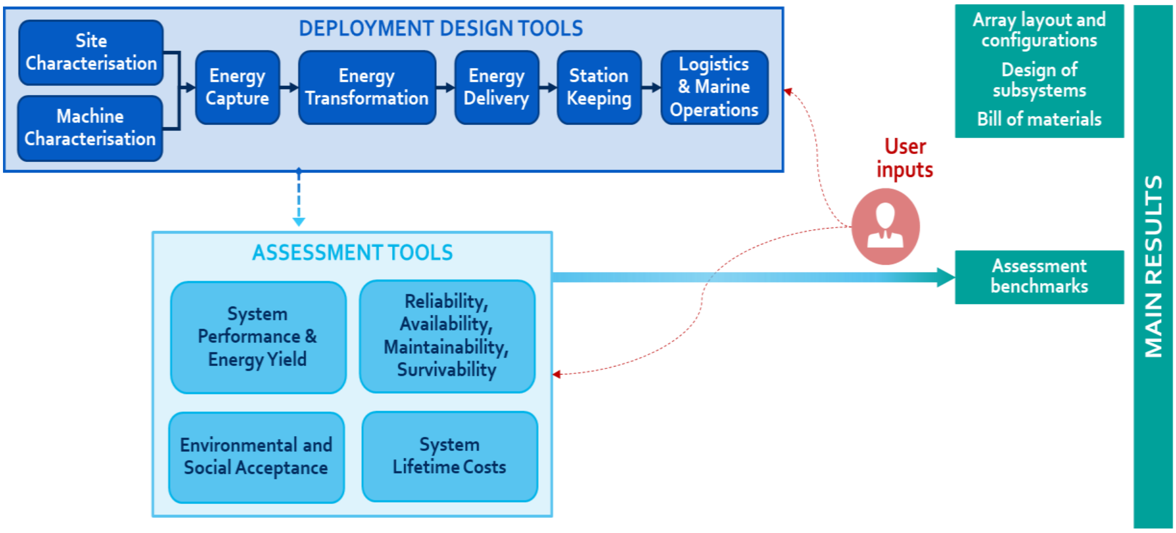


FIGURE 6.1 VS3 DTOCEANPLUS MODULES, MAIN LINKAGES AND OUTPUTS

6.2.3 VS 3 WAVE ENERGY ARRAY DESCRIPTION

6.2.3.1 SITE DESCRIPTION

The considered site was BiMEP, located in the Basque Country, off the coast in Armintza. It is an open-sea infrastructure for technical testing of Marine Renewable Energy prototypes. The test centre covers an area of 5.2 km² with depth varying from 50 to 90m. The North and central zone are primarily composed of sand with some presence of rock, whereas the East and West zones are primarily characterized by rock. BiMEP is equipped with four berths of 13.2kV/5MW, each connected to the grid.

6.2.3.2 DEVICE DESCRIPTION:

The MARMOK-A-14's characteristics are reported below:

- Category: Floating Oscillating Water Column Wave Energy Converter;
- Size: Length 46.9m, Width=14m , Draft = 40.4m;
- TRL: 8;

- prime mover: buoy steel structure;
- PTO: Air turbine, Wells type;
- mooring & foundation: catenary moorings and drag-embedded anchor; and
- Control strategy: speed rotation and torque.

A drawing of the technology with its mooring system, reporting sizing and components' nomenclature is shown in Figure 6.2.

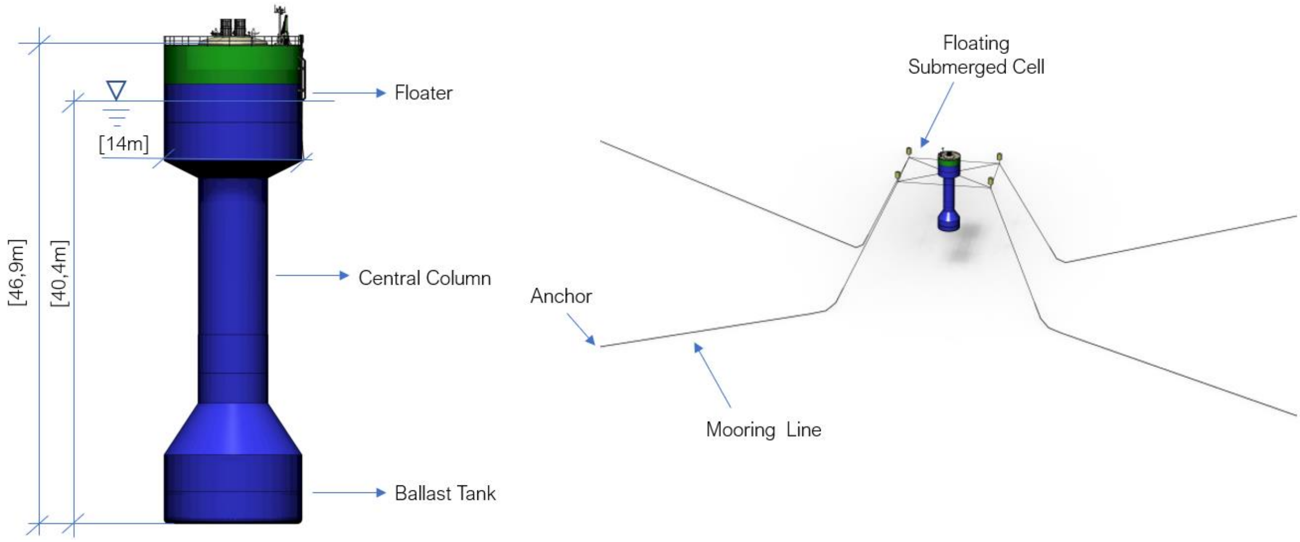


FIGURE 6.2 MARMOK-A-14 COMPONENT SIZE AND NOMENCLATURE (LEFT) AND GENERAL OVERVIEW OF THE SYSTEM FOR A SINGLE DEVICE (RIGHT)

Array layout

The array is composed of 8 devices. The WEC farm annual energy production assessment started by considering the selected WEC layout reported in Figure 6.3. Two distances between devices have been taken into account d1 and d2, in addition to two wave headings, WH1 and WH2, and were analysed as reported in Figure 6.3. A sensitivity analysis at these distances as well as at the wave headings will be carried out in order to select the best configuration.

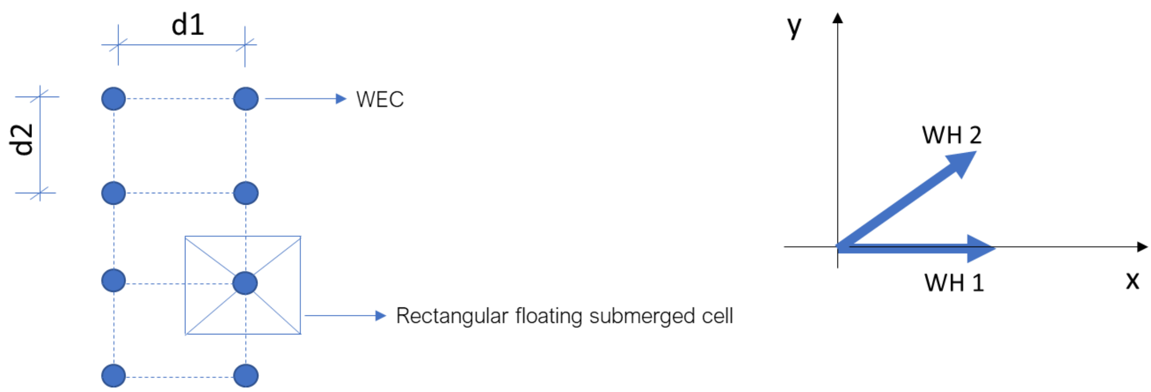


FIGURE 6.3 MARMOK-A-14 ARRAY LAYOUT AND WAVE HEADINGS

Mooring

The mooring system configuration consists of a floating submerged cell (one for each device) made of steel wire rope connected to the wave energy converter by four polyester ropes. The set of submerged cells are connected to the seabed by catenary lines. The weight of the suspended catenary lines is supported by buoys, minimising the heaving interaction between mooring system and the wave energy converter.

The solution presented allows for a shared mooring configuration among the devices in an array.

Foundation

The type of foundation is based on a drag-embedded anchor attached to each catenary line of the shared mooring system.

Electrical connection

The electrical connection scheme is reported in Figure 6.4.

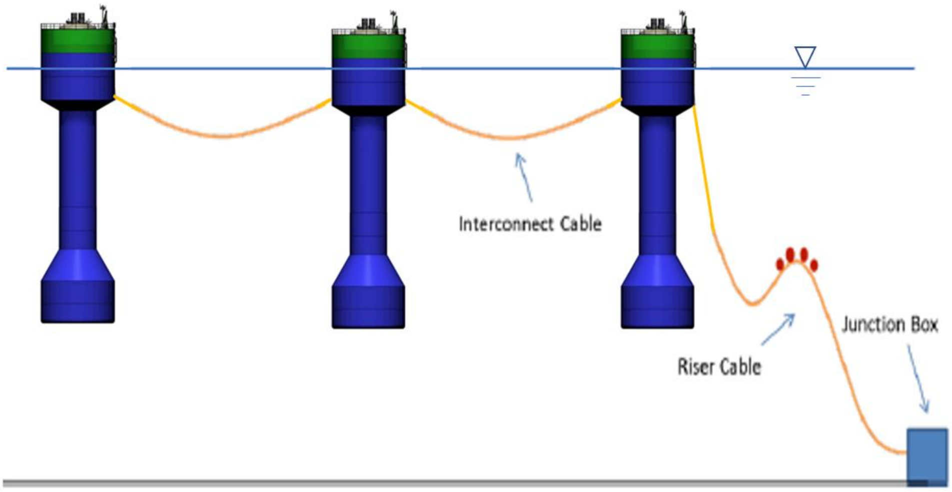


FIGURE 6.4 ELECTRICAL CONNECTION SCHEME

6.2.4 VS3 INPUT VARIABLES

In this section the input variables required for the tested deployment design tools are reported.

6.2.4.1 DEPLOYMENT DESIGN TOOL: MC

In the MC module the input variables are general information, body dimensions and the model definition. MC allows for having a hydrodynamic characterization of the bodies involved in the system. In particular, the OWC wave energy converter model was used and the following inputs were defined for the hydrodynamic analysis:

- Range of wave angles;
- Range of wave frequencies;
- Water depth;
- Degrees of freedom.

As the objective is the extracted power assessment of WEC array, the option "Estimate Farm Interaction matrixes" was activated.

The hydrodynamics of the system is based on two interacting bodies, one represented by a floating buoy and the other one represented by the oscillating water column. The physical characteristics such as centre of gravity and inertia were defined for both bodies. The meshes of the bodies were defined in order to calculate with Nemoh code, based on Boundary Element Method, which is integrated into the tool.

Implemented meshes for the two bodies are reported in Figure 6.5.

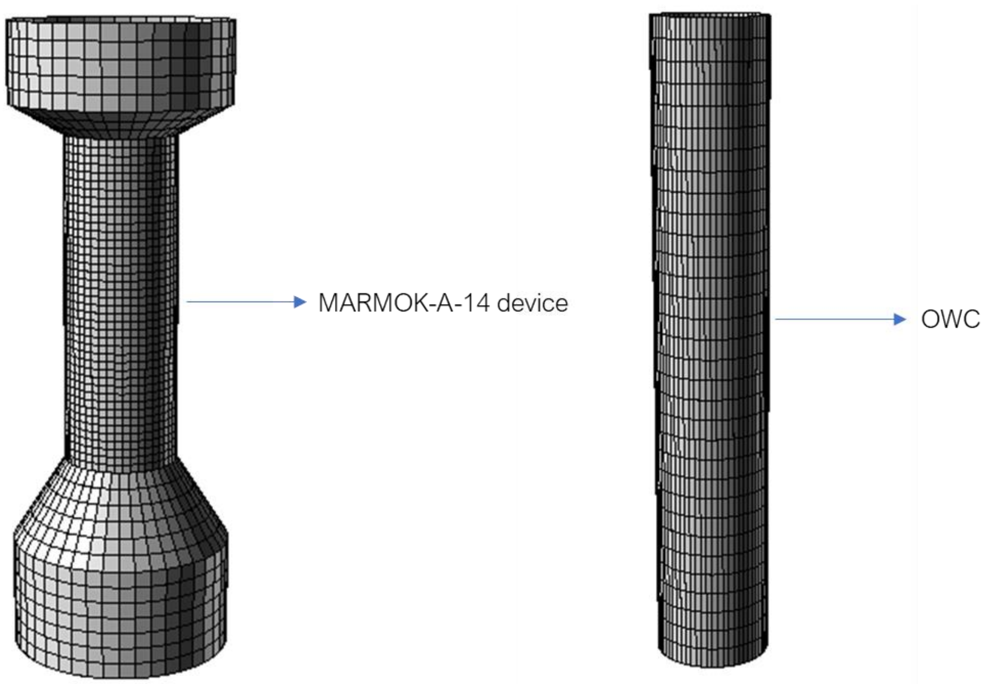


FIGURE 6.5 MESHES OF MARMOK-A-14 (LEFT) AND OWC (RIGHT)

The final input, important for the hydrodynamic interaction between the bodies and therefore directly related to the extracted power, was the definition of PTO acting as a damping between the bodies.

6.2.4.2 DEPLOYMENT DESIGN TOOL: EC

Part of the EC input data are the output of the MC tool. Once the lease area was defined, the WECs' layout was defined. The distances d1 and d2 (see Figure 6.3) were varied in order to study the influence of distance on captured power. The value d2 has been fixed as the same as d1. Five values have been considered and reported in the next section together with the results.

6.2.5 VS3 RESULTS

6.2.5.1 DEPLOYMENT DESIGN TOOL: MC

Among the most important results to report are the trends in terms of hydrodynamic parameters and excitation forces. In particular, the hydrodynamic parameters in heave (added mass and radiation damping) and the heave's excitation force with its related phase angle are reported in Figure 6.6 and Figure 6.7, respectively.

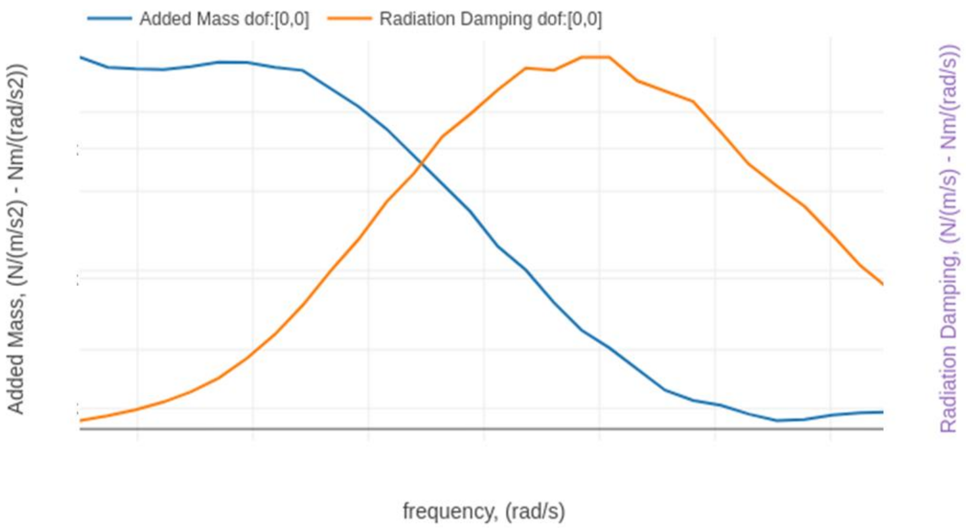


FIGURE 6.6 ADDED MASS AND RADIATION DAMPING TRENDS FOR HEAVE D.O.F.

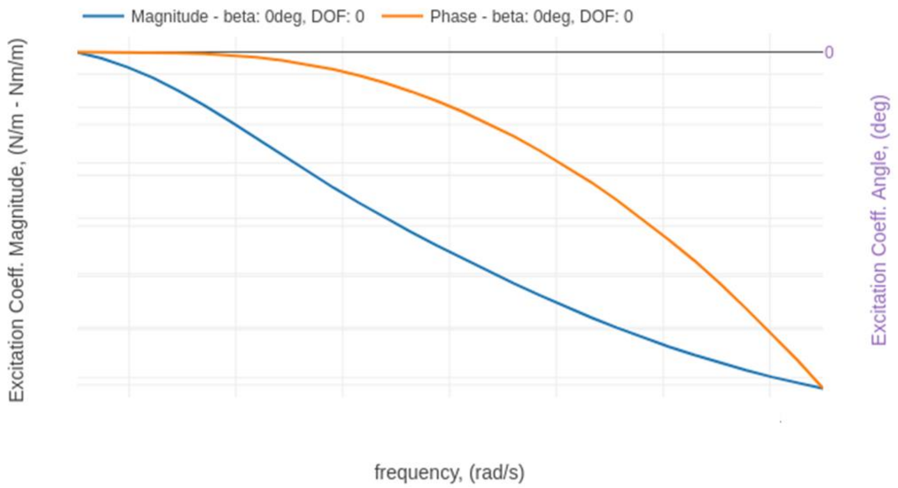


FIGURE 6.7 EXCITATAION FORCE AND PHASE ANGLE TRENDS FOR HEAVE D.O.F.

6.2.5.2 DEPLOYMENT DESIGN TOOL: EC

As reported in Figure 6.8, it is possible to detect negligible differences (taking into account the Y-axis scale) when varying the distance between devices (10, 25, 50, 100 and 200 m) with d1 equal to d2, whereas no differences have been found for the two wave headings detected (90 and 45 deg). If one paid attention only to the trends and not to the values, it could be said that a maximum of AEP Farm is detected at a distance between devices equal to 100 m. This value seems to be very high and it does not represent a value from which a convergence can be reached because at 200m the AEP Farm decreases.

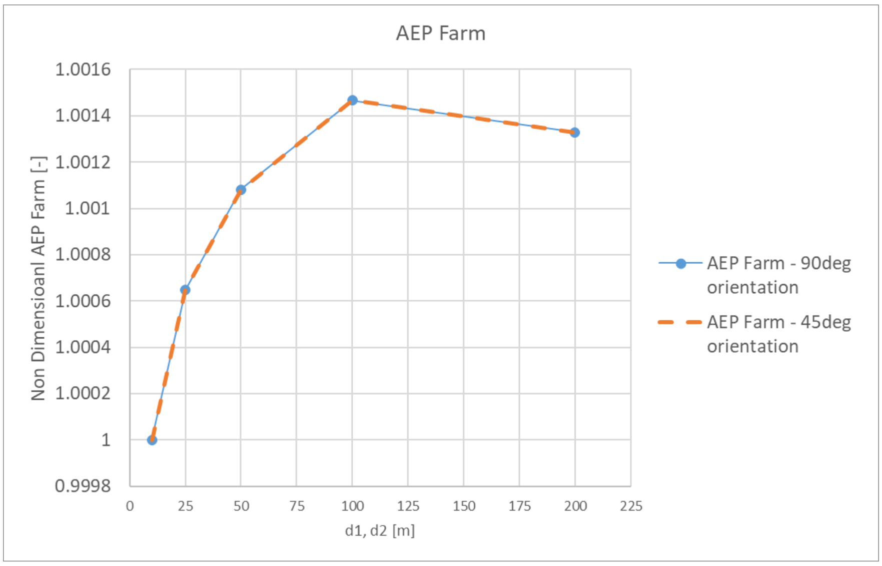


FIGURE 6.8 NON-DIMENSIONAL AEP FARM VERSUS INTERDISTANCE BETEWEN DEVICES

At the stage of development of the EC module at the time of use, neither the distance between devices nor the wave heading were found to have any influence on the annual energy production of a WEC farm.

The results presented for the selected WEC layout are similar to the ones obtained for the other ones selected, reason for which they have not been commented on in this report.

6.2.5.3 VS3 OVERALL IDOM FEEDBACK

SC has been run at complexity level 1 and 2 in the integrated mode. The requested inputs were the same in the two levels but in both cases it was not possible obtain results to generate input for EC. The calculation time at the same level of complexity was variable and sometimes the module was in overflow and it was cumbersome to generate output, maybe due to bad communication with the catalogues.

Due to the inconsistency of the outputs, an occurrence matrix was introduced in SC at complexity level 3, possible only in standalone mode; reason for which also MC and EC were also run in standalone mode.

The results obtained in the modules tested (SC, MC and EC) appeared to be in the range of what could be expected for the studies performed. The steps offered by the software under modular deployment and assessment tools, together with the complexity level, imply a very straightforward technology development process, allowing for a deeper analysis of the main design fields of any marine energy converter.

Efforts have been concentrated on validating the annual energy production of a WEC farm, which represents surely the first important step for a WEC farm developer.

Through MC, hydrodynamic parameters and excitation forces were obtained with trends similar to the ones expected for the analysed hydrodynamic system.

About Energy Capture (EC) module, the results obtained appeared to be consistent with the inputs introduced. However, the variation of the different parameters of the layout, as distances between devices and wave headings, appeared to have no effect on the annual energy production of a WEC farm even using complexity 3 level.

7. SUMMARY OF DEMONSTRATION ACTIVITY OUTCOMES

Industrial partners involved in Task T7.4 ran the defined demonstration scenarios described in Sections 4 to 6 to validate the applicability of the tools for concept creation and selection, technology development and farm deployment and optimizations. The set of demonstration activities is presented in Table 7.1.

TABLE 7.1 VALIDATION SCENARIOS PER MODULES AND COMPLEXITY LEVEL

DTOceanPlus - Validation activity summary																											
Industrial partners	SI	SG	Module Complexity Level																					SPEY	RAMS	SLC	ESA
			SC			MC			EC			ET			ED			SK			LMO						
CPO	*X*	*X*																	$2^{(p)}$			$2^{(p)}$					
EGP	*X*		1		3	1		3	1		3		2			2			$2^{(p)}$								
WES	*X*																										
IDOM				2	$3^{(sa)}$			$3^{(sa)}$			$3^{(sa)}$																

sa: stand alone mode
p: partially tested

7.1 QUANTITATIVE ASSESSMENT OF DTOCEANPLUS SUITE OF TOOLS

Task 7.4 industrial partners evaluated the overall software features and its user-friendliness. The results from the evaluation were processed and are presented in an aggregated way, per evaluation category:

1. Installation
2. Operation:
3. Integration:

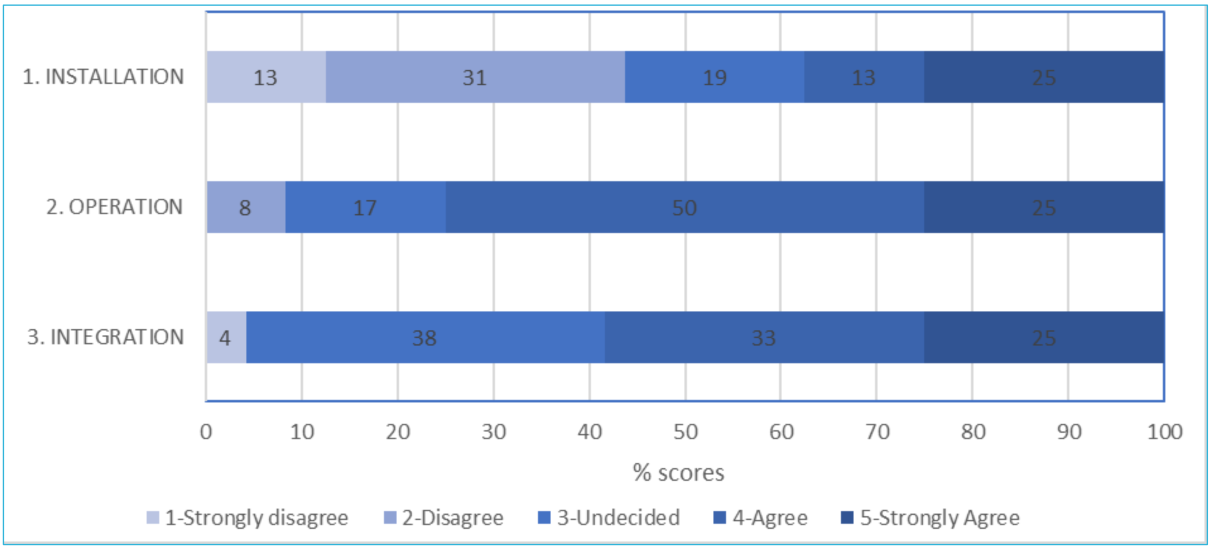


FIGURE 7.1 OVERALL EVALUATION STATEMENT SCORES (%)

Installation statements are reported for an easier interpretation of the following graphs:

TABLE 7.2 SOFTWARE EVALUATION QUESTIONS ON INSTALLATION OF GLOBAL SUITE OF TOOLS

ID	Installation statement
5.1	The installation guideline is clear and easy to complete
5.2	The installation process was completed without errors
5.3	The software can be run from my local workstation without any issue
5.4	The prerequisite specifications were clear (memory, OS, processor…)

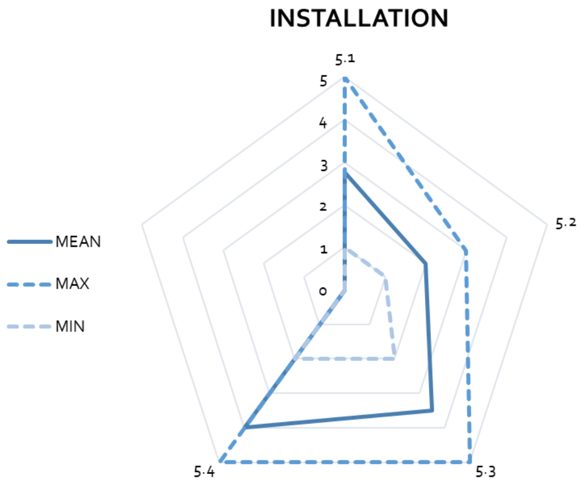


FIGURE 7.2 INSTALLATION - MIN/MEAN/MAX SCORES

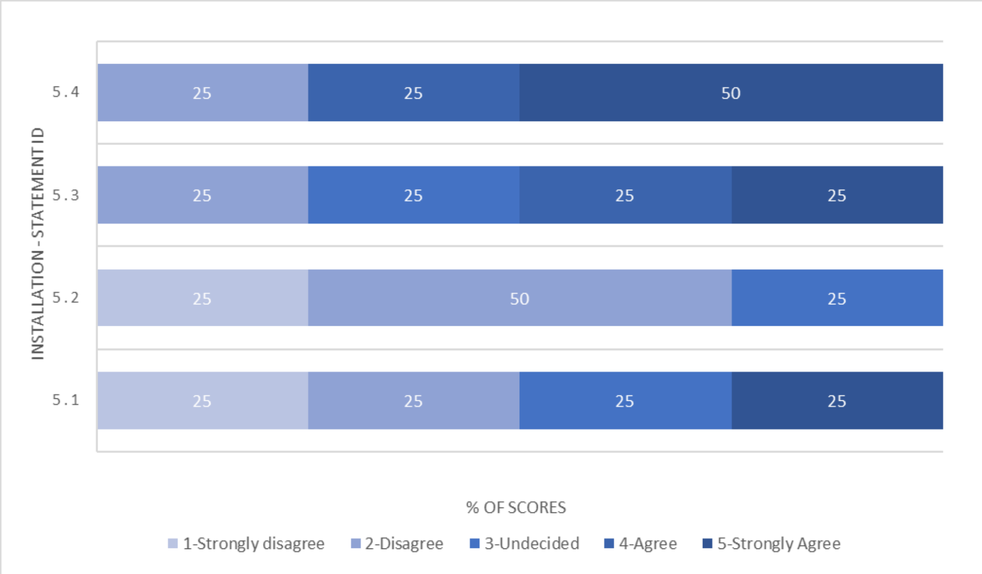


FIGURE 7.3 INSTALLATION STATEMENT SCORES (%)

The scores relevant to installation criteria highlight the users' difficulties in putting in practice installation guidelines and procedures. This occurred in particular in the first installation version in mid-July. The following software release v0.9.1 was allowed the user to install the software in a more user friendly way with only minor issues related to the docker.

Operation statements are reported for an easier interpretation of the following graphs:

TABLE 7.3 SOFTWARE EVALUATION QUESTIONS ON OPERATION OF GLOBAL SUITE OF TOOLS

ID	Operation statements
5.5	The process of inputting and formatting data is expected with the level of detail
5.6	The description/guidance is useful for learning how to use the software
5.7	I am satisfied with the overall speed of computation
5.8	The tool met my needs in the relevant stage of the project lifecycle
5.9	The modular architecture of the software provides me with the freedom to focus on the relevant design needs
5.10	The tools can handle the complex data flows efficiently for the relevant stage of the project lifecycle

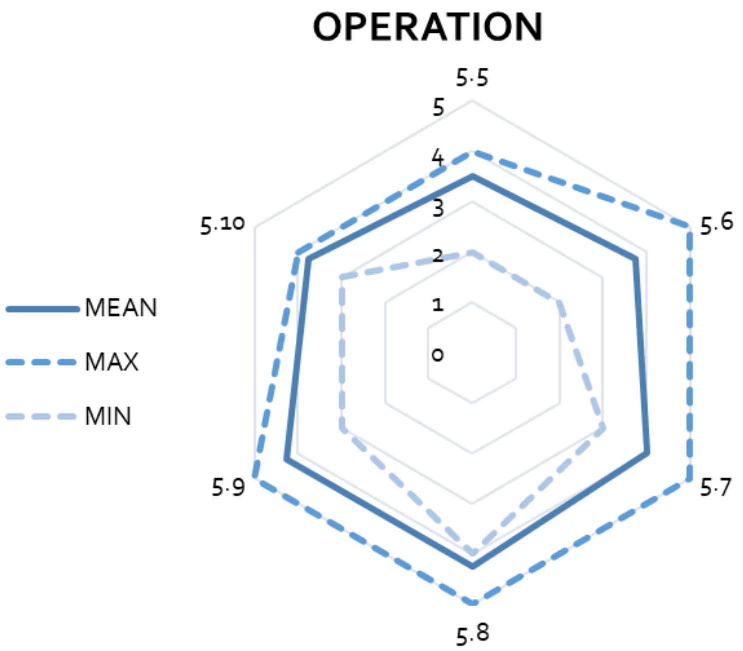


FIGURE 7.4 OPERATION - MIN/MEAN/MAX SCORES

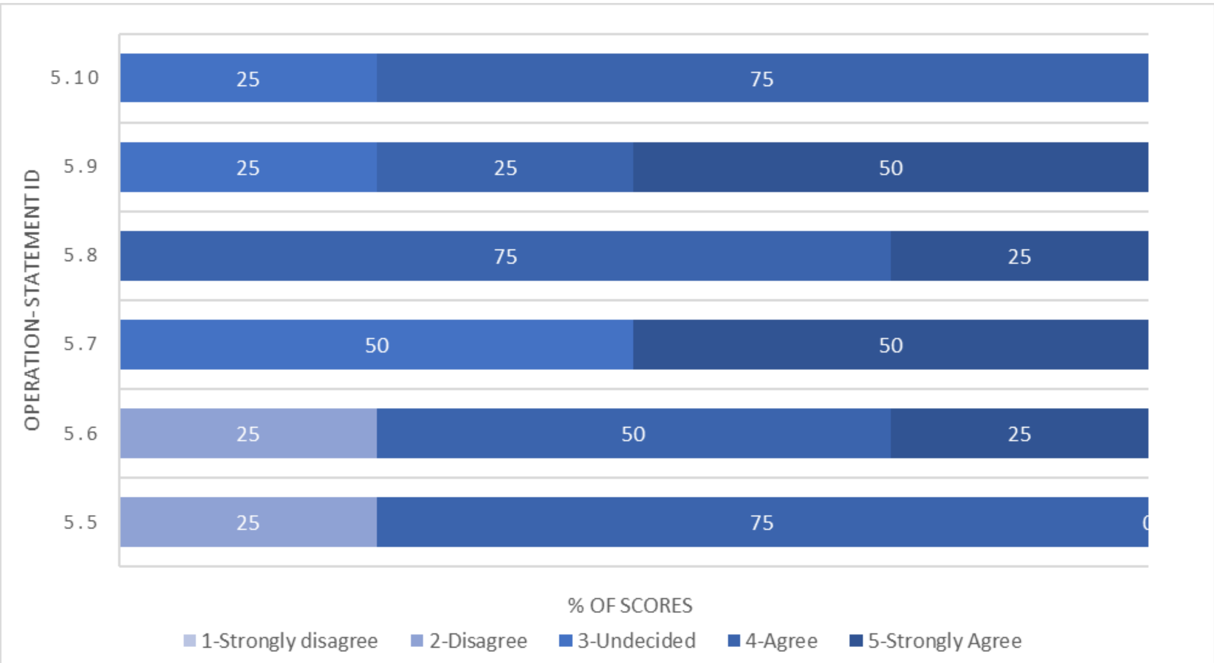


FIGURE 7.5 OPERATION STATEMENT SCORES (%)

The industrial partners provided average neutral feedback about data inputting and formatting data guidelines because a more detailed description of data formatting must be included in the tutorial. Industrial users needed support from the module developers to formatting the input data correctly. Same feedback is obtained relevant to the data flow handling.

The partners were satisfied with the speed of the software whilst running wave array projects; the way the software meets user needs at specific stages of the project lifecycle, and good results relevant to the modularity of the software that met users needs for running the module of interest in a standalone mode.

TABLE 7.4 SOFTWARE EVALUATION QUESTIONS ON INTEGRATION OF GLOBAL SUITE OF TOOLS

ID	Integration statements
6.1	I was able to use the tools in Standalone mode
6.2	I was able to use the tools in Integrated mode
6.3	The tools are flexible to use for different design objectives and iteration cycles.
6.4	Dataflow is efficient
6.5	The user has control of the design process
6.6	The tools can handle the complex data flows efficiently for the relevant stage of the project lifecycle

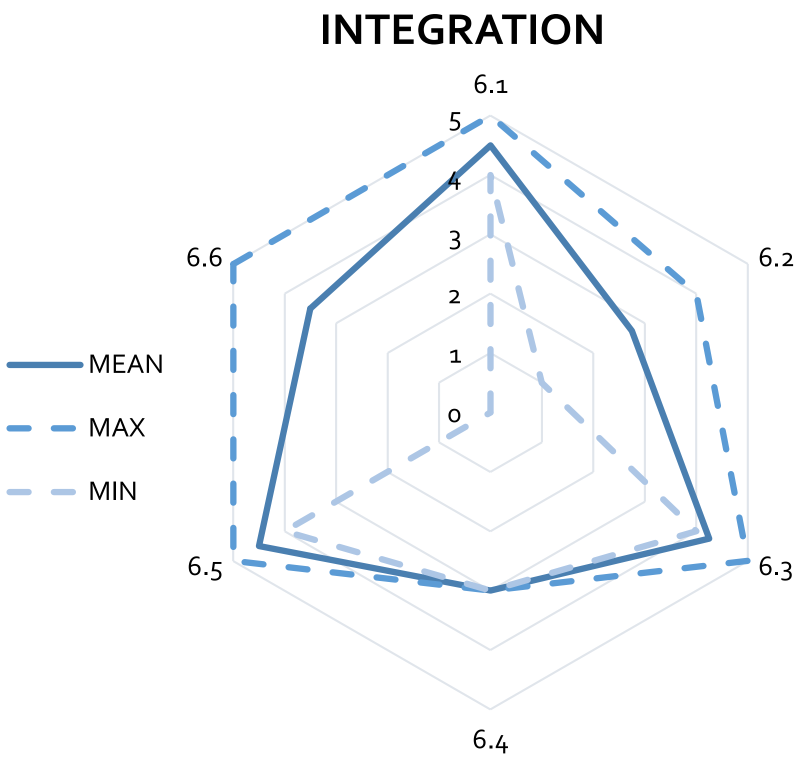


FIGURE 7.6 INTEGRATION - MIN/MEAN/MAX SCORES

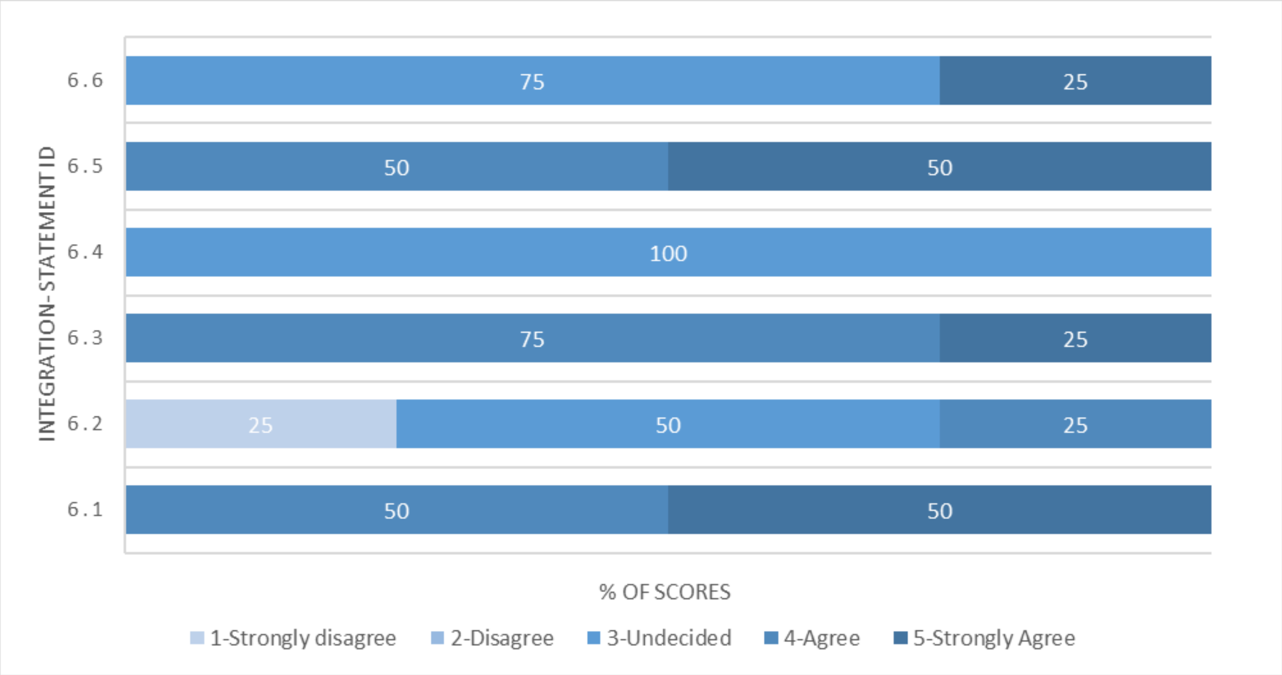


FIGURE 7.7 INTEGRATION STATEMENT SCORES (%)

A neutral feedback has been provided by the users relevant to the use of the integrated mode and the data flow interconnectivity. These two statements are of course related to each other and the score is due to the

difficulties encountered while running the validation scenarios at integrated mode where errors occurred in fetching data from other modules. This problem was peculiar of the v0.9.1 and then solved in the final version.

Strong positive feedback has been obtained in the statements dealing with flexibility of the modules, the control the design process achieving the design objectives.

7.2 STRUCTURED INNOVATION TOOL VALIDATION STATEMENT: USER ASSESSMENT

The SI tool helped identify and prioritise the voice of the most critical stakeholders. Due to its structured approach, the tool enabled structured thinking and facilitated the partners to find new technology development pathways. The tool directs the users to input their target values, which creates transparency of the areas in technology development that should be of the highest priority. Working towards ideality helps the user prioritise their next steps in technolo gy development. The SI tool effectively guided the user in setting up the innovation case by helping define clear objectives and relevant functional or design requirements necessary for objectives achievement.

There is a value-added in using the SI tool in the first instance because the tool gives an order to the innovation process while keeping rationale and creative approaches at the same time. The rationale part sits in the QFD and FMEA method that requires objective data. Comparing the functional requirement targets to the "state of the art" helps find innovation areas worth investing in. The most creative part is the TRIZ method, particularly at the final step where specific innovative solutions must be found, starting from general "Inventive Principles" suggested by the tool to eliminate conflicting requirements. Another value-added benefit of the tool is the use of FMEA at the concept or design stage. Usually, the details required to run an FMEA analysis increase as the technology matures; knowing failure modes for a TRL 1 concept and the severity of occurrence is very difficult. However, the FMEA within the SI tool enabled the partners to assess the "potential" failure modes of the functional structure (design or new concept) rather than the system's physical structure possible performed at a more mature level (operations and processes).

At the earliest stages, the QFD is useful, as it starts with the highest level considered 'top level objectives' and makes the user think about what they are trying to achieve, which can have a big impact on guiding the user in particular at early stages. The TRIZ tool is helpful for both early and late stage technologies. Although, the user is more likely to implement big design changes at early stages than at late stages.

The steps within the tool are clear for most parts, and the Data Sources tab on the right-hand side is very helpful in providing the user with the definition of terms. The documentation is clear, and no external software or tools were used.

The QFD/TRIZ and FMEA results can be exported to Excel, which is useful for post-processing and graphic representation of the results. The QFD/TRIZ, in particular, which splits the outputs in the Excel sheet into different tabs, is very user friendly. FMEA results can be used during design reviews.

During the validation activity of DTOceanPlus, the SI tool did not meaningfully help the user find real new solutions to improve the relevant design but rather helped find innovative pathways. The QFD within the SI tool is dependent on the user filling in the details of the design options. In some cases, the small input data availability was insufficient for defining the problem in all its extent and variability. There is a recommendation to ensure multi-level interactions with multi-disciplinary teams to provide different experiences, perspectives, datasets and insights to facilitate objective assessment.

TRIZ Inventive problem-solving difficulties encountered by the users are directly related to the implementation of DTOceanPlus, but the method itself, which was a novel method for most of the industrial partners, requiring background knowledge or training. The least user-friendly step of this method was the last one. After finding the general solution relevant to the conflicting functional requirements, the user must translate the "TRIZ generic inventive principles" into wave energy-specific solutions that fit the specific validation scenario problem. As mentioned above, multi-disciplinary teams need to be capable of translating the proposed generic inventive principles into specific solutions relevant to the design intent.

FMEA method is more difficult to be applied at the concept creation phase or early-stage of design– low TRL devices due to the low degree of device details upon which to apply the failure modes analysis. The tool, however, guides the user to consider potential failure modes related to the functions of the system.

Regarding QFD within the SI tool, the designers are strongly encouraged to use the tool with multidisciplinary teams within their company to focus on important requirements and to take into account all the necessary functional requirements to carry out their innovation activity to all its extent.

Regarding the TRIZ method, it would be useful to have in the help menu a brief description of both the 39 general problem conflicts (contradiction matrix) and the 40 "inventive principles" in order not to look for additional documentation outside the tool. Examples of successful TRIZ real cases from different industrial sectors would also guide the user in translating inventive principles into specific customized solutions.

7.3 STAGE GATE TOOL VALIDATION STATEMENT: USER ASSESSMENT

Generally, the feedback from the validation scenarios indicated that the Stage Gate tool is easy to use and straightforward to understand. The industrial partners found that the tool provides a useful framework and checklist to understand where they are in the technology development pathway. As a structured approach, the Stage Gate was found to support a fair evaluation of sub-systems or devices from the earliest stages of development.

A useful feature of the Stage Gate tool was its ability to use it integrated with other modules. This enabled data outputted from other modules to feed into the required inputs of the tool. The Improvement Areas feature helped the teams to identifying weaknesses in the technology and where innovation can be considered. The bespoke report generation feature was found to be a useful addition to the tool, as it summarised all the assumptions, scoring and criteria of the analysis.

Overall, industrial partners indicated that, in general, the Stage Gate tool provides a useful checklist valuable for technology developers, especially in guiding younger organisations. More specific feedback is provided below:

- Points in the Activity Checklist are well-considered and comprehensive.
- The stage gate selection seemed accurate and aligned with expectations
- Improvement areas are identified well and are consistent with the stage gate being assessed
- The Study Comparison feature requires two or more completed stage gate studies to run, and since there is no default study built into the tool, this feature cannot be used unless the user inputs two studies themselves. Perhaps in future iterations of the tool, this could be something that is included.
- Some data fields were missing for input metrics for Stages 4 and 5 when the tool was used for validation – however, this may have been fixed before the final release.

7.4 DEPLOYMENT DESIGN TOOLS VALIDATION STATEMENT: USER ASSESSMENT

The aim of the tool allows for an advantageous comparison of technologies or design alternatives in a very useful way. “Entities” are useful to build up different studies and compare results.
The design steps and information flow are well structured and the user is well guided through the process. The modular architecture of the software implies a very straightforward technology development process, allowing for a deeper analysis of the main design fields of any marine energy converter.

The ability to select the complexity level of the modules makes the design process very adaptable to the needs of the user at each stage. Overall, the differences regarding the needs of each complexity level are easily identified, leading to a rapid assessment of the detail level of the results.

The results obtained in the modules tested appeared to be in the range of what could be expected for the studies performed. SC module results are useful because a statistical analysis of the time series is provided. MC module provide useful hydrodynamic analysis and resonance condition of the device. About EC module, once the site and the machine had been characterized, different array layouts were evaluated and the results obtained appeared to be consistent with the inputs introduced.

Databases helped in carrying out validation use case when no proprietary data was available. SC catalogues have been used regarding seabed geology and marine species and they run without any issue.

The SC, MC and EC modules allowed for easy export of the results. However, the Energy Capture module appeared to have the option of providing a .pdf file with the results but it was not foreseen the possibility of extracting the raw data that makes up the plots.

The modules are managed by the Docker software which uses great part of computer memory and a lack of memory leads to software instability or unavailability of the modules.

The operation of the software and the utility of the results for comparison are highly dependent on the capacity of correctly reproducing the inputs, a task that with the current information provided by the interface is challenging without the help of a developer.

When using the EC module for WEC array layout optimization the variation of the different parameters of the layout appeared to have no effect on the results even using complexity 3 level. Besides no warning or error appeared even when placing the devices in contact or occupying the same space, having no influence on the results.

When using database in the LMO module the user have access to a list of vessels with valuable information, such as day rates, free deck area and vessel crane capacity. Apart from the vessels suggested by the tool, three other vessels were added to the database to more fully represent the current fleet available to service European sites. For these three additional vessels, only the crane capacity and the deck areas were provided. The day rates (min and max) were calculated based on linear cost functions obtained using DTOceanPlus data

DTOceanPlus provides only one value of fuel consumption per vessel. However, vessels have different fuel consumption values for different operations (e.g. mobilization, transit, DP trials). In order to account for a more accurate fuel emission, one vessel – which the fuel consumption per operation was available – was taken as an example and the fuel emissions was calculated. For this case a relationship between real fuel emissions and DTOceanPlus fuel emissions was defined and applied for all the other vessels.

About the output files the Energy Capture module appeared to have the option of providing a .pdf file with the results but it was not foreseen the possibility of extracting the raw data that makes up the plots.

If more information about the input were included, the software could allow for a more rapid comparison of technologies that can surely help any design development process, independently of its maturity level. It would be useful to have SC and MC modules in an "open" configuration as per the other modules so to be modified along a study without the necessity of creating a new project and create new SC and MC entities.

The understanding of the input data could be enhanced by adding pop-up help windows (e.g. MC module: dimension and model input) providing prompt explanations.

There are still some refinement to be done to increase stability of the calculation (MC module matrix interaction and EC array optimization functionality), and to obtain a better interconnection among the modules in order to have a smooth internal data flow without any data flow error.

Warnings could be introduced to guide the users in case of wrong data inputting. In EC module a warning or error message could be implemented if devices are too closed spaced or overlapping.

A general recommendation about output accessibility that would ease the process would be to unifying the method of data exportation for every module, so there would be no need to analyse each particular process for data exportation.

8. CONCLUSIONS

The four industrial partners CorPower, IDOM, Enel Green Power and WES carried out the validation activity of the DTOceanPlus suite of design tools. Those represents respectively the three main user categories in the marine energy sector: the technology developers, the project developers and the public investor who are in need of such a complete tool to solve real cases of wave energy projects.

According to industrial partners expectations five real use-case validation scenarios have been taken into account to validating the DTOceanPlus suite of tools.

The validation scenarios were characterized by the use of real wave energy deployment sites and for this detailed input data was used. Same approach was adopted for the selection of suitable wave technologies. The wave energy devices used in the project are ranked at mid-high technology readiness level. Some of these utility scale devices like MARMOK-A (TRL6) by IDOM and C4 by (TRL7) CorPower have already been tested at large scale in real sea environment and design data have been used individually by the partners during the validation activity.

Industrial partners shared the validation scenario results in the limit of the confidentiality constraint and provided their feedback on the use of the modules and an overall evaluation focused on these evaluation criteria: Installation, operation and modules interconnection.

In the first phase of the validation activity the first installation procedure (v0.9.0) was difficult to follow and the users also found some difficulties on selecting the right computer and operating system. The second version at mid-July (v0.9.1) permitted everybody equipped with a workstation multiprocessor to install the software in an easier way and start the operation phase.

This phase was characterized by an intense team working activity where the industrial partner started using the tools at different complexity level sharing with other partners every error, inconsistency, input data formatting problems etc. The academic partners run the modules too in order to accelerate this debugging activity. The modules developers provided with users feedback improved the module functionality and interconnection of data by releasing tens of versions per module till the end of the project.

Four software installation versions have been released from July the 2nd (v0.9.0) and August the 31st when the DTOceanPlus suite of tools has been finally released for public use with version V1.1.1.

The modules were tested according to the relevant use-case validation scenarios in order to achieve relevant use case objectives.

All the design tools have been tested: the Structured Innovation tool Stage Gate tools and the Design Deployment tools: SC, MC, EC, ET, ED, SK, LMO.A set of these were tested in a stand-alone mode others at integrated mode. Stand alone was adopted in the first phase of mainly for solving integration issues among the modules occurring at the maximum complexity level (complexity 3).Nevertheless the stand-alone mode demonstrated the software flexibility based upon its modular architecture adding, on the other side, some manual work for input/output file management.

The software final version permitted the user to run wave energy use-cases in integrated mode appreciating the great potentiality of the modules functionalities and a smooth data flow among the modules.

All the industrial partners expressed their interest to supporting the further development of the software bringing it from the maturity level TRL6 achieved at the end of this project to the the fully commercial release.

9. REFERENCES

[1] V. Nava and P. Ruiz-Minguela, "DTOceanPlus Deliverable 2.3 "Demonstration Methodology"," Tecnalia, Bilbao, 2019.

[2] Marques, M.I., Marques, M.J., Lopes Filipe, N., Kessler, P., Lourenço, T., Tunga, I., Ruiz-Minguela, P., Nava, V., Noble, D., Henderson, J., Luxcey, N., Germain, N., "DTOceanPlus Deliverable 7.2 "Detailed description of demonstration scenarios"," 2019.

[3] Tunga, I., Ball, K., Tatlock, B., Abrahams, M., Khan, H., Sanchez-Lara, M.J., Ruiz-Minguela, P., Robles, E., "DTOceanPlus Deliverable 3.3 "Testing and verification results of the Structured Innovation tool - Beta version"," 2020.

[4] Marques, M.I., Langiano, S., Harvey, C., Lourenço, T., Ruiz-Minguela, P., Nava, V., Henderson, J., Hudson, B., Tunga, I., Fonseca, F., "DTOceanPlus Deliverable 4.3 "Testing and verification results of the Stage Gate tool - Beta version"," 2020.

[5] Marques, M.I., Langiano, S., Harvey, C., Lourenço, T., Tunga, I., Ruiz-Minguela, P., Nava, V., Grispiani, L., Robles, E., Lopez Mendia, J., Fonseca, F., Luxcey, N., Michelet, N., Araignous, E., Ferri, F., Noble, D. , "DTOceanPlus Deliverable 5.8 "Testing and verification results of the Deployment Design tools - Beta version"," 2021.

[6] Marques, M.I., Langiano, S., Harvey, C., Lourenço, T., Tunga, I., Ruiz-Minguela, P., Nava, V., Fonseca, F., Amaral, L., Safi, G., Araignous, E., Yang, Y., "DTOceanPlus Deliverable 6.6 "Testing and verification results of the Assessment Design tools – beta version"," 2021.

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

[8] Ruiz-Minguela, P., Nava, V., Sanchez-Lara, M.J., Ivanovna, N., Etxaniz, P., Murray, J., Peron, Q., Wills, T., Noble, D., Henderson, J., Tunga, I., Luxcey, N., Fonseca, F., "DTOceanPlus Deliverable 7.3 "Scenarios Input Data"," 2020.

[9] CorPower Ocean, "UMACK- Universal Mooring, Anchor & Connectivity Kit Demonstrator," 2021. [Online]. Available: https://www.corpowerocean.com/projects/umack/. [Accessed 15 09 2021].

[10] J. Beyá, M. Álvarez, A. Gallardo, H. Hidalgo, C. Aguirre, J. Valdivia, C. Parra, L. Méndez, F. Contreras, P. Winckler and M. Molina, "Atlas de Oleaje de Chile," Universidad de Valparaiso, 2016.

[11] V. S. Neary, M. Lawson, M. Previsic, A. Copping, K. C. Hallett, A. LaBonte and D. Murray, "Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) technologies-SAND2014-9040," Sandia National Laboratories, 2014.

10. ANNEX I: VS1.1 INPUT DATA – CPO

Lead Partner	CPO
Other Partners Interested	WES
Technical Support Partner	ESC
Technology	CPO
Total Power/ Number of devices	300kW / 1
Subsystem/Component	
Intended Site	Aguçadoura Portugal

DATA AVAILABILITY	QUANTITY	UNIT	FORMAT	AVAILABLE?	SOURCE	CONFIDENTIAL?	ADDITIONAL INFORMATION ON FORMAT
INTENDED SITE							
WAVE DATABASE							
Wave timeseries							
Wave height	Hs	m	2D array: Hs, time	YES	Simulation model	YES	
Wave period	Tp, Te	s	2D array: T, time	YES	Simulation model	YES	
Wave direction, coming from	dp	deg	2D array: deg, time	YES	Simulation model	YES	
Wave energy flux	CgE	kW/m	2D array: CgE, time	YES	Simulation model	YES	
Wave statistics							
Empirical probability distribution							
Wave height	Hs			YES	Info from supplie	YES	DNV Metocean Report
Wave height & period	Hs/Tp			YES	Info from supplie	YES	DNV Metocean Report
Wave height & direction	Hs/dp			YES	Info from supplie	YES	DNV Metocean Report
Wave height, period & direction	Hs/Tp/dp			YES	Info from supplie	YES	DNV Metocean Report
Extreme return values							
Wave height	Hs		Number	YES	Info from supplie	YES	DNV Metocean Report
Wave period	Tp		Number	YES	Info from supplie	YES	DNV Metocean Report
Wave contours	Hs/Tp		Polygon	YES	Info from supplie	YES	DNV Metocean Report
CURRENT DATABASE							
Current timeseries							
Current velocity	mag	m/s		NO			
Current direction, coming from	theta	deg		NO			
Current zonal velocity	U	m/s		NO			
Current meridional velocity	V	m/s		NO			
Current available power	Cp	kW/m^2		NO			
Current statistics							
Empirical probability distribution							
Current velocity	mag	m/s		YES	Info from supplie	YES	DNV Metocean Report
Current direction, coming from	theta	deg		YES	Info from supplie	YES	DNV Metocean Report
Current velocity & direction	mag/theta	m/s, deg		YES	Info from supplie	YES	DNV Metocean Report
Extreme return values							
Current velocity	mag	m/s		YES	Info from supplie	YES	DNV Metocean Report
Current profile	mag, z	m/s, m		YES	Info from supplie	YES	DNV Metocean Report
WIND DATABASE							
Wind timeseries							
10m-wind velocity	mag10	m/s		NO			
10m-wind direction, coming from	theta10	deg		NO			
10m-wind zonal velocity	U10	m/s		NO			
10m-wind meridional velocity	V10	m/s		NO			
10m-wind gusts	gust10	m/s		NO			
Wind statistics							
Empirical probability distribution							
10m-wind velocity		m/s		YES	Info from supplie	YES	DNV Metocean Report
10m-wind direction, coming from		deg		YES	Info from supplie	YES	DNV Metocean Report
10m-wind velocity & direction		m/s, deg		YES	Info from supplie	YES	DNV Metocean Report
Extreme return values							
10m-wind velocity		m/s		YES	Info from supplie	YES	DNV Metocean Report
10m-wind gusts		m/s		YES	Info from supplie	YES	DNV Metocean Report
WATER LEVEL DATABASE							
Water level timeseries							
Water surface fluctuation, relative to MSL	XE			YES	Info from supplie	YES	DNV Metocean Report
Water level, relative to bottom	WLEV			YES	Info from supplie	YES	DNV Metocean Report
Water level statistics							
Water level, relative to bottom	WLEV			YES	Info from supplie	YES	DNV Metocean Report
Empirical probability distribution	WLEV			YES	Info from supplie	YES	DNV Metocean Report
Extreme return values	WLEV			YES	Info from supplie	YES	DNV Metocean Report
SEABED PROPERTIES							
Bathymetry file	x, y, z		UTM coordinates	YES	Info from supplie	YES	
Contours							
Lease area shapefile							
Corridor shapefile							
Competing Use of space: Existing cable routes			Line	YES	Info from supplie	YES	
Competing Use of space: Existing vessel routes			Line	NO			
Competing Use of space: No-go areas			Polygon	NO			
Seabed type			Points				
Soil type/classification				YES	Info from supplie	YES	
Soil submerged density				YES	Info from supplie	YES	
Undrained cohesion				YES	Info from supplie	YES	
Effective friction angle				YES	Info from supplie	YES	
Layer thickness				YES	Info from supplie	YES	
Disctance to rock bed				YES	Info from supplie	YES	
MARINE SPECIES FILE							
Receptors	R	R, probability		NO			To be covered in the environmental monit
Initial environmental condition	E	E, number		NO			To be covered in the environmental monit
Endangered species	S	S, probability		NO			To be covered in the environmental monit
PRIME MOVER / DEVICE							
DIMENSIONS							
Draft	d	m		YES		YES	Own design data (CPO)
Height	h	m		YES		YES	Own design data (CPO)
Width	w	m		YES		YES	Own design data (CPO)
Length	L	m		YES		YES	Own design data (CPO)
Submerged Volume	V	m^3		YES		YES	Own design data (CPO)
Wetted Area	WFA	m^2		YES		YES	Own design data (CPO)
Mass and Inertial properties	M			YES		YES	Own design data (CPO)
Footprint radius	FR	m		YES		YES	Own design data (CPO)
HYDRODYNAMICS							
Tidal							
Tip Speed Ratio							N/A
Power Coefficient Curve							N/A
Trust Coefficient Curve							N/A
Cp/Ct Velocity Definition							N/A
Orientation Angle							N/A
Cut In Velocity							N/A
Cut Out Velocty							N/A
Heading Angle Span							N/A
Bidirectional Turbine		Boolean	Yes/no				N/A
Wave							
Capture Width Ratio				YES		YES	Own design data (CPO)
Tp capture width				YES		YES	Own design data (CPO)
Hs capture width				YES		YES	Own design data (CPO)
Wave angle capture width				YES		YES	Own design data (CPO)
Additional Damping							
Additional Stiffness							
Multibody - other dofs							
Hydrodynamic Matrices (added mass, radiation damping, External excitation)							
POWER SETTINGS & STATIONKEEPING							
Rated Capacity	PWR			YES		YES	Own design data (CPO)
Connector Type				YES		YES	Own design data (CPO)
Control Subsystem failure Rate				NO			
Mooring Stiffness				YES		YES	Own design data (CPO)
Foudation preferred type				YES		YES	Own design data (CPO)
OPERATIONS							
Max Installation Water depth		m	float	YES		YES	Own design data (CPO)
Min Installation Water depth		m	float	YES		YES	Own design data (CPO)
Min interdistance perpendicular to waves/current		m	float	YES		YES	Own design data (CPO)
Min interdistance parallel to waves/current		m	float	YES		YES	Own design data (CPO)
COST							
Device Subsystem cost		€					
POWER TAKE-OFF							
MECHANICAL CONVERSION							
Type of mechanical conversion			String - turbine, hyd	YES		YES	Own design data (CPO)
Manufacturer reference			String	YES		YES	Own design data (CPO)
Main dimensions		m	Height x Width x Le	YES		YES	Own design data (CPO)
Weight		kg	Scalar	YES		YES	Own design data (CPO)
Primary materials		Material	String	YES		YES	Own design data (CPO)
Transmission ratio			Scalar	YES		YES	Own design data (CPO)
Rated power	Pnom	kW	Scalar	YES		YES	Own design data (CPO)
Speed range		rpm, m/s	Scalar - max, min	YES		YES	Own design data (CPO)
Input force, torque range		N, Nm	Scalar - max, min	YES		YES	Own design data (CPO)
Maximum stroke (only for linear systems)		m	Scalar	YES		YES	Own design data (CPO)
Efficiency		%	Curve	NO			
Cost		€	Scalar	YES		YES	Own design data (CPO)
Failure rate			Scalar	NO			
ELECTRICAL CONVERSION							
Type of electrical conversion			String - PMG, DFIG,	YES		YES	Own design data (CPO)
Manufacturer reference			String	YES		YES	Own design data (CPO)
Number of pole pairs			Scalar				
Insulation class		A, B, F, H	String	YES		YES	Own design data (CPO)
Main dimensions		m	Scalar - Diameter x	YES		YES	Own design data (CPO)
Weight		kg	Scalar	YES		YES	Own design data (CPO)
Primary materials		Material	String	YES		YES	Own design data (CPO)
Rated power	Pnom	kW	Scalar	YES		YES	Own design data (CPO)
Nominal voltage	Vnom	V	Scalar	YES		YES	Own design data (CPO)
Nominal intensity	Inom	A	Scalar	YES		YES	Own design data (CPO)
Maximum voltage	Vmax	V	Scalar	YES		YES	Own design data (CPO)
Maximum torque	Tmax	Nm	Scalar	YES		YES	Own design data (CPO)
Maximum speed		rpm, m/s	Scalar	YES		YES	Own design data (CPO)
Efficiency		%	Curve	YES		YES	Own design data (CPO)
Power factor		%	Scalar	YES		YES	Own design data (CPO)
Cost		€	Scalar	YES		YES	Own design data (CPO)
Failure rate		-	Scalar	NO			
GRID CONDITIONING							
Type of grid conditioning			String - e.g. back-to	YES	Info from supplie	YES	
Manufacturer reference			String	YES	Info from supplie	YES	
Main dimensions		m	Scalar - Height x Wi	YES	Info from supplie	YES	
Weight		kg	Scalar	YES	Info from supplie	YES	
Primary materials		Material	String	YES	Info from supplie	YES	
Rated power	Pnom	kW	Scalar	YES	Info from supplie	YES	
Switching frequency		Hz	Scalar	YES	Info from supplie	YES	
Grid voltage	Vcc	V	Scalar	YES	Info from supplie	YES	
Grid resistence	Rce	ohm	Scalar	YES	Info from supplie	YES	
Efficiency		%	Curve	YES	Info from supplie	YES	
Power factor		%	Scalar	YES	Info from supplie	YES	
Cost		€	Scalar	YES	Info from supplie	YES	
Failure rate		-	Scalar	NO			

CONTACT DETAILS

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Naval Energies terminated its participation on the 31st of August 2018 and
EDF terminated its participation on the 31st of January 2019.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 785921