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

Deliverable D7.8

Demonstration Results of Integrated Design Tools for Tidal Energy

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EXECUTIVE SUMMARY

This document, "D7.8 Demonstration results of integrated design tools for Tidal Energy", is a deliverable of the DTOceanPlus project funded by the European Union's H2020 Programme under Grant Agreement №785921.

The objective of Task 7.5 was to carry out at least three tidal 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 three industrial partners, Orbital Marine Power, Sabella, and Nova Innovation, who validated the DTOceanPlus suite of tools against five tidal energy validation scenarios.

These tidal 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 tidal energy use cases using the DTOceanPlus suite of tools with real input regarding their technology. The objectives focused on different aspects such as: improving a floating tidal energy connection subsystem, assessing and demonstrating the development stage of two tidal energy technologies, validating tidal array deployments at different sites to provide third party evidence, and validating scaling up of a tidal energy drivetrain for a deployment site.

During the validation activity from July to the end of August, the industrial partners worked in a strong cooperative way 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 31 August.

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ABBREVIATIONS AND ACRONYMS

AD	Assessment Design
DD	Deployment Design
DO	Design Objective
Dx.x	Deliverable x.x from a task or work package
EC	Energy Capture
ED	Energy Delivery
ESA	Environmental and Social Acceptance
ET	Energy Transformation
FMEA	Failure Mode and Effects Analysis
KPI	Key Performance Indicator
LCOE	Levelised Cost of Energy
LMO	Logistics and Marine Operations
MC	Machine Characterisation
MRE	Marine Renewable Energy
OE	Ocean Energy
OMP	Orbital Marine Power
O&M	Operation and Maintenance
PaaS	Platform as a Service
PMSG	Permanent Magnet Synchronous Generator
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
TRL	Technology Readiness Level
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

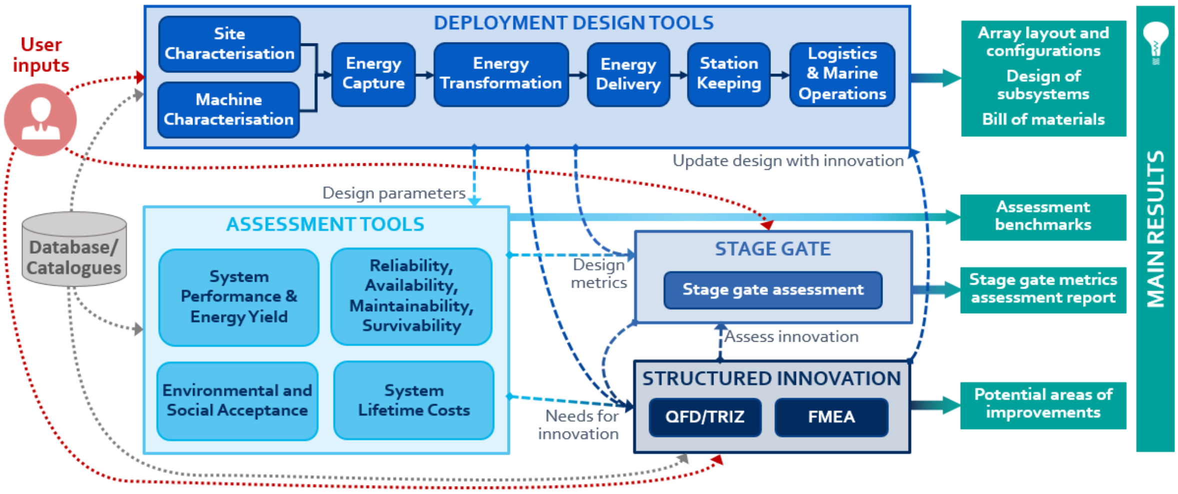


FIGURE 1.1 DTOCEANPLUS MODULES, MAIN LINKAGES, AND OUTPUTS

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 will be 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 T7.5 Demonstration of tidal energy scenarios. The task proposed that at least three tidal energy demonstration cases be run to showcase the applicability of the tools to concept generation and selection, technology development, and farm deployment and optimisation. Where possible, cases with strong links across the tools were selected, and priority was given to real cases (cases at highest TRL) where real data can be obtained and used. A comprehensive analysis of results and comparison with the industrial partners' expectations was carried out to extract useful information on the impact potential of tidal 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 tidal 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 the array, device, and subsystem level with wave and tidal technologies. Within this, some VSs had sub-scenarios with different industrial partners. These are summarised in Table 2.1.

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-PB500, New concept Site: Agoucadura: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: Agoucadura:Portugal	**VS4: Structured Innovation** Lead: Orbital Subsystem: Orbital O2 Connectors Site: EMEC Berth 5

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.

2.2 COLLECTION OF DATA

The plan for this task was to use as much real data 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 circumstances. However, this could be equivalent to testing at an earlier stage in project development, where this data may not readily be available.

Future testing of the tools may use the data identified from these tasks.

2.2.1 CONFIDENTIAL DATA

The input data belonging to the partners involved in the validation task T7.5 and the output data obtained by the partners during the use of the software are all considered confidential data, and for this reason, these will not be disclosed to the other partners of the project.

Partners involved in T7.5 provided general information and public data for explaining the validation use-case, the relevant site and their tidal energy technology. Results of the validation scenarios are presented in this document:

- Normalised results: where possible, partners showcased the software output as relative results (percentage) based on confidential reference values. These give evidence of the potentialities of the software and the type of results that can be obtained using the software.
- Evaluation form scores: partners were requested to fill in an evaluation form that assigns scores (1:strongly disagree to 5: strongly agree) to the DTOceanPlus tools' functionalities and the overall suite of tools. These scores were processed and presented, putting in evidence points of strength and improvement areas.
- Qualitative description of the tools' performance, assessed against the engineering judgement of the industrial partners.

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, D4.3, D5.8, & D6.6 [3, 4, 5, 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.

The draft documentation for each module produced for deliverables D3.3, D4.3, D5.8, & D6.6, was updated and transferred to the GitLab repository alongside the code. Additionally, overall documentation was written to explain the overall suites of tools, including the main module and catalogues. This documentation was used to support the demonstration activities and continuously updated with feedback. This included some troubleshooting guides and updated installation instructions.

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. 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

ID	Statement
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
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. DTOCEAPLUS 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 server on a company intranet. 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 T7.5 are listed in Table 3.2.

TABLE 3.2 INDUSTRIAL PARTNERS' SOFTWARE AND HARDWARE USED FOR INSTALLATION

T7.5 partner	PC	Work-station	Server	Internet connection	Nº Processors	CPU	RAM (GB)	Operating System
Nova	PC Specialist	–	–	On	8	Intel Core I7 vPro @2.8GHz	16	Windows 10 Professional
Sabella	–	HP Z230 Tower Workstati on	–	On	8	Intel(R) Xeon(R) CPU E3-1246 v3 @ 3.50 GHz	24	Windows 10 Professionel
OMP	Dell XPS	–	–	On	8	Intel® Core™ i7-7700HQ CPU @ 2.8GHz	16	Windows 10 Professional
UEDIN	HP Elitebook	–	–	On	8	Intel Core I7 vPro 8th Gen @2.1GHz	32	Windows 10 Education 64 bit
UEDIN	HP Elitebook	–	–	On	4	Intel Core I7 vPro @2.8GHz	16	Windows 10 Education 64 bit

3.3 DTOCEANPLUS RELEASE HISTORY

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

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 the use of 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

Module's version development during the validation phase			
#	Module	02/07/2021	31/08/2021
14	CM	v0.0.1	v1.0.1
15	MM	v0.0.1	v1.0.0

As noted in the subsequent validation scenario sections, there were many issues with the installation of the tools, including the required Docker software. Some, but not all, of these were resolved during the testing phase.

Sabella had many issues with Docker for Windows, setting parameters for virtualisation requested admin rights, and a memory issue could be solved using an administrator session to launch Docker. In the Windows Task Planner, they had to create a task to launch it automatically with administrative rights at the start of the computer. The need for administrative rights to use Docker should be clearly documented; the "Prerequisite" section from the current documentation did not help to troubleshoot. Installation of some modules was quite hard as well, needing support from the software developers. In addition, as the "Check for update" in the Windows installer was not working properly, there was still a need to tell the newest version manually. Orbital also had many issues with Docker, mostly with the use requirement of Hyper-V service.

Despite the support, many repeated attempts on multiple PCs and the use of the latest DTOceanPlus software versions, Nova could not successfully install a reliably stable version of the integrated tools during T7.5, as discussed in section 6.1. The University of Edinburgh provided a working version of the software that enabled Nova validation of VS6.1.

4. VS4 STRUCTURED INNOVATION TOOLS WITH A TIDAL SUBSYSTEM

Validation Scenario 4 is representative of a **Tidal Energy technology** and the **Structured Innovation Tool** at a **Subsystem level**. Orbital Marine Power (OMP), the validation partner, identified the following Design Objectives:

4.1 VS4 ORBITAL

4.1.1 VS4 DESIGN OBJECTIVES

To improve existing technologies, e.g. Reduced CAPEX, without changing the design features which are critical to success

To give a structured process for making design decisions and potentially highlight innovations not yet considered or dismissed. The ideal metric for comparison is LCOE improvements, but also considering timescales and engineering investment

4.1.2 VS4 USE CASES AND USER STORY

The use case for Orbital's validation is to explore options for further development of the Orbital O2 connection system. Throughout the development process of Orbital's floating tidal turbine technology, many different options have been designed and developed with no option fully identified as being the best option. The purpose of the validation case is to use the structured innovation tool. The tool is ideally suited to process the data Orbital have gathered through years of development.

Due to integration issues with the tools and time limitations, the validation study could not be carried out with the full suite of tools. The Structured Innovation tool was only used in standalone mode. The main validation was carried out using the QFD and the FMEA modules, the TRIZ tool was used, but the user was not confident in how best to input the data and how to get the best use of it. Further use is required to get more comfortable and confident in the operation and outputs of the process.

A full FMEA study was carried out with the current mooring system deployed on the O2 tidal turbine, see Figure 4.1.

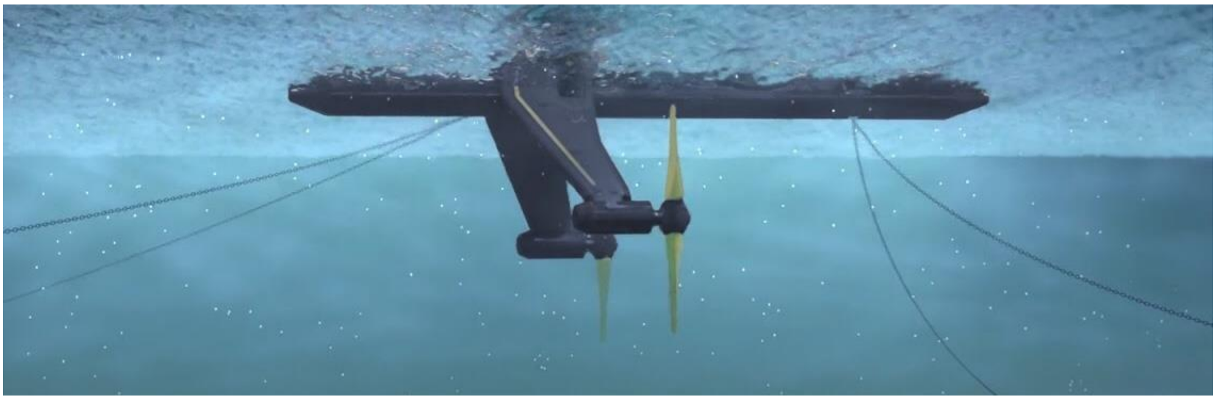


FIGURE 4.1 ORBITAL O2 TIDAL TURBINE AND MOORING SYSTEM

4.1.3 VS4 DTOCEANPLUS TOOLS SELECTION

Only the SI tool in standalone mode was used for the validation in VS4. Note that the SI tool works at all levels of technology maturity and does not have separate complexity levels

TABLE 4.1 TOOLS TESTED IN VS4

Module/tool	
Structured Innovation (SI)	✓

4.1.4 VS4 INPUT DATA DESCRIPTION

Due to confidentially, Orbital cannot include specific details of the data input nor the specifics of the outputs. The validation was carried out by inputting data from a number of mooring systems and configurations developed by Orbital and several options under consideration for development for future turbines. All of the data used has been developed and understood in house. Data for previous turbines has been well validated through a systematic method of analysis and testing. Most of the data input into this validation is from well-understood mooring systems.

4.1.5 VS4 RESULTS

The results from the QFD tool were very illuminating; it allowed Orbital to be able to compare several various options in an easy to view and understand manner. The progression through the tool is easy to navigate and understand what is required at all stages.

In the customer requirement stage, the user can specify a number of requirements and give them a ranking in order of importance. For the mooring validation, examples of the requirements are cost, installability and maintainability. The importance value is somewhat confusing as there is no pre-defined scale; it seems to be unlimited as to what can be set to. It would be more beneficial if it was a predefined scale such as 1-10.

The functional requirement tab is the same as the previous, with the ability to specify how to measure the ability to reach the customers' requirements. Again, there is the ability to input as many variables and requirements as required. From further use of the tool, it is apparent that the more you can put into this section, the better, even if considered trivial, as the solutions are very extensive, so the more detail that can be compared against will give more valuable output.

The impacts tab is very simple and straightforward to fill out, although the more that you put into the functional requirements tab means that the matrix that you are filling out gets larger; it was found that ten or more functional requirements defined make the screen a little cluttered and hard to read on the screen. This is the same for the correlations tab; more inputs make it a little more difficult to follow and fill out.

One of the recommendations from the module developer was that although many functional requirements can be defined to meet the customer requirements, only the most important impact requirements for satisfying the customer requirement should be carried forward for further assessment.

The TRIZ tab seemed straightforward to fill out; however, some description of the importance of the TRIZ class would be beneficial; with little prior knowledge of TRIZ, I was not sure how best to classify each requirement.

The solutions tab again is nice and straightforward to fill out. With the Orbital validation case, seven options that are well known and understood were input. This tab is a very good one-stop shop that helps to collate all of the information around each option.

The report tab is again very well structured and easy to follow and understand. The requirement tab does a really good job of summarising the inputs, as does the deviation from targets, which shows how each option compares against the other. Although all of the data was thoroughly understood and documented prior to the study, it was very interesting to see it all collated in one place and very beneficial to see it in one place. The ideality of solutions tab takes the previous tab and really displays it in an easy-to-understand format.

The results displaced in the ideality of solutions tab were very much in line with what Orbital had devised in house. The top two options were by far ahead of the others, which was as expected, and these are the options that have been progressed into further development. Interestingly the options that have been disregarded have never really been ranked in terms of potential viability; two of the options had a relatively high score compared to the others that have been disregarded. This has led to a potential for re-evaluation of the options to possibly lead to the re-design and implementation of future turbines' design.

The FMEA tool is a fantastic addition to the SI toolbox. Previously, FMEA has been a rather unstructured process. This tool really gives a fantastic flow to filling out each section, ensuring that the user is able to truly focus on the section being completed. This helps to ensure that all eventualities are considered and analysed properly. The results of the FMEA tool compared favourably with the FMEA carried out in-house. The time taken to fill out the FMEA tool was considerably less than the in-house FMEA, clearly showing the benefit of the tool whilst still providing similar results.

5. VS5 STAGE GATE TOOL WITH TIDAL DEVICE

Validation Scenario 5 is representative of a **Tidal Energy Technology**, using the **Stage Gate tool** at the **Device level**. Orbital and Sabella considered two sub-scenarios.

5.1 VS5.1 ORBITAL

5.1.1 VS5.1 DESIGN OBJECTIVES

Perform a stage gate assessment for a device using an embedded and standalone mode of the Stage Gate design tool and produce a report for the developer to demonstrate their performance

5.1.2 VS5.1 USE CASES AND USER STORY

Technology developers/ designers: Assess their device in the context of an array, i.e. assessing LCOE(£/kWh) to prove what stage their technology is at and highlight any areas which were unable to be assessed with a link to the Structured Innovation tool for further development.

5.1.3 VS5.1 DTOCEANPLUS TOOLS SELECTION

Due to time constraints, Orbital could not run the SG tool in integrated mode with the deployment design tools. Note that SG works at all levels of technology maturity and does not have separate complexity levels.

TABLE 5.1 TOOLS TESTED IN VS5.1

Module/tool	
Stage Gate (SG)	✓

5.1.4 VS5.1 INPUT DATA DESCRIPTION

The SG assessment carried out by Orbital was only the activity checklist option. This was carried out in an in-depth manner as required, with all inputs considered as intently as possible to ensure that the results truly reflected the companies stage in development.

5.1.5 VS5.1 RESULTS

Though only able to carry out the activity checklist, it enabled Orbital to gain valuable outputs from the use of the tool. It aligned basically with where we think our technology currently stands in terms of development and highlighted a number of areas that have possibly in the past been dismissed but more recently have been identified as areas that should be focused on. Consequently, Orbital are looking at options to carry out some of the activities unticked.

Orbital have very much taken a structured approach to the development of our technology. This has involved numerous tests of scale models, both in real world environments and in tank environments. As the technology approaches commercialisation, the SG tool has highlighted the importance of continued scale/tank tests. This is something that was not considered of high importance for the company going forward prior to carrying out the SG assessment. Following on for these results Orbital have since engaged with various testing partners to open dialogue with regards to continued tank testing. Previous tests have generally been focused on the overall system performance, this has enabled Orbital to gain a very high degree of confidence our numerical models, so future tests are likely to focus on subsystems, such as moorings and PTO performance.

With regards to the PTO performance it is likely that Orbital will be looking to engage partners for some PTO bench tests, unfortunately due to commercial sensitivity more detail cannot be included in this report. One of the main drivers for exploring the avenue of PTO testing was the outcome of the SG tool which highlighted its importance for control.

5.2 VS5.2 SABELLA

5.2.1 VS5.2 DESIGN OBJECTIVES

The Design Objective for VS5.2 is to perform a stage gate assessment for a device using the embedded and standalone mode of the Stage Gate design tool and produce a report for the developer to demonstrate their performance

5.2.2 VS5.2 USE CASES AND USER STORY

Technology developers/ designers: Assess their device in the context of an array, i.e. assessing LCOE(£/kWh) to prove what stage their technology is at and highlight any areas which were unable to be assessed with a link to the Structured Innovation tool for further development.

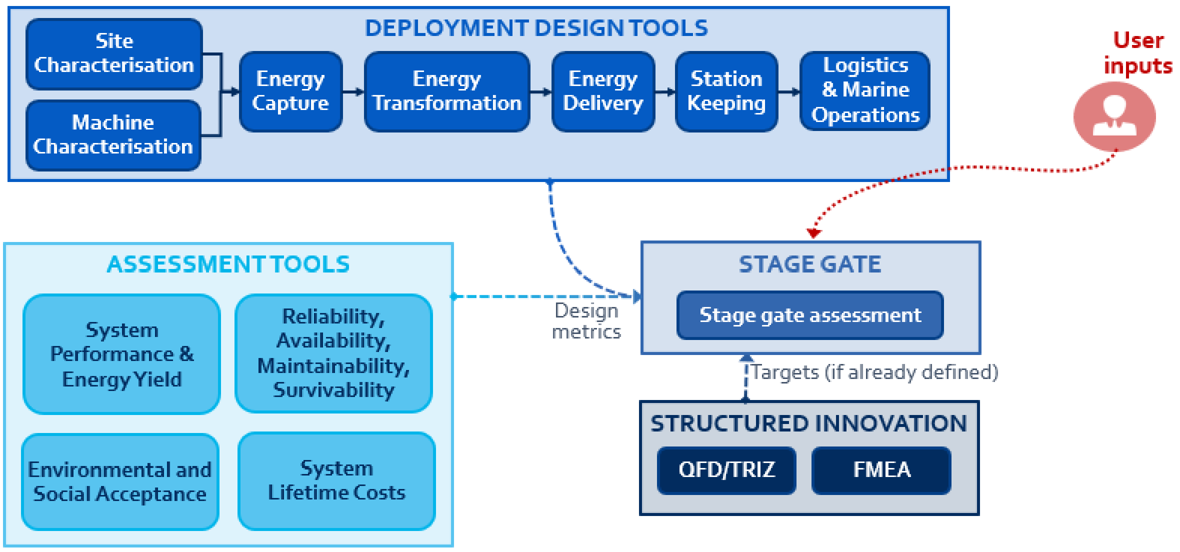


FIGURE 5.1 MAIN FLOW OF INFORMATION BETWEEN MODULES IN VS5.2.

5.2.3 VS5.2 DTOCEANPLUS TOOLS SELECTION

All of the Deployment and Assessment tools (except ESA & RAMS), plus the Stage Gate, Main Module, and Catalogues, were tested for VS5.2, as shown in Table 5.2. Note that SG works at all levels of technology maturity and does not have separate complexity levels.

TABLE 5.2 TOOLS AND COMPLEXITY LEVELS TESTED IN VS5.2

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)			✓
Logistics and Marine Operations (LMO)			✓
System Performance and Energy Yield (SPEY)			✓
System Lifecycle Costs (SLC)			✓
Environmental and Social Acceptance (ESA)	Unable to run ESA at complexity 1		
Reliability, Availability, Maintenance, Survivability (RAMS)	Unable to run any of RAMS tools at complexity 1		
Stage Gate (SG)	✓		

5.2.4 VS5.2 INPUT DATA DESCRIPTION

The project includes two D15-500 SABELLA, 500 kW turbines, shown in Figure 5.2, and is located in the Fromveur straight in Brittany (France), shown in Figure 5.3. This site has been partly defined using SABELLA data, five-year timeseries for the velocity field and water height in the lease area. The bathymetry, seabed type, roughness length, and endangered species were defined using the catalogue data provided with the software.

The turbine is a three-bladed, 15m diameter rotor, driving a PMSG through a direct-drive transmission. The nacelle is held by a gravity-based metallic support structure, shown in Figure 5.2.

The two devices are directly linked to the land via a 2km electric cable with no substation. The site is shown in Figure 5.3 and Figure 5.4.

SABELLA has defined an advanced corrective and preventive maintenance plan for this project.

FIGURE 5.2 COMPUTER MODEL OF SABELLA D15-500 TIDAL TURBINE AND SUPPORT

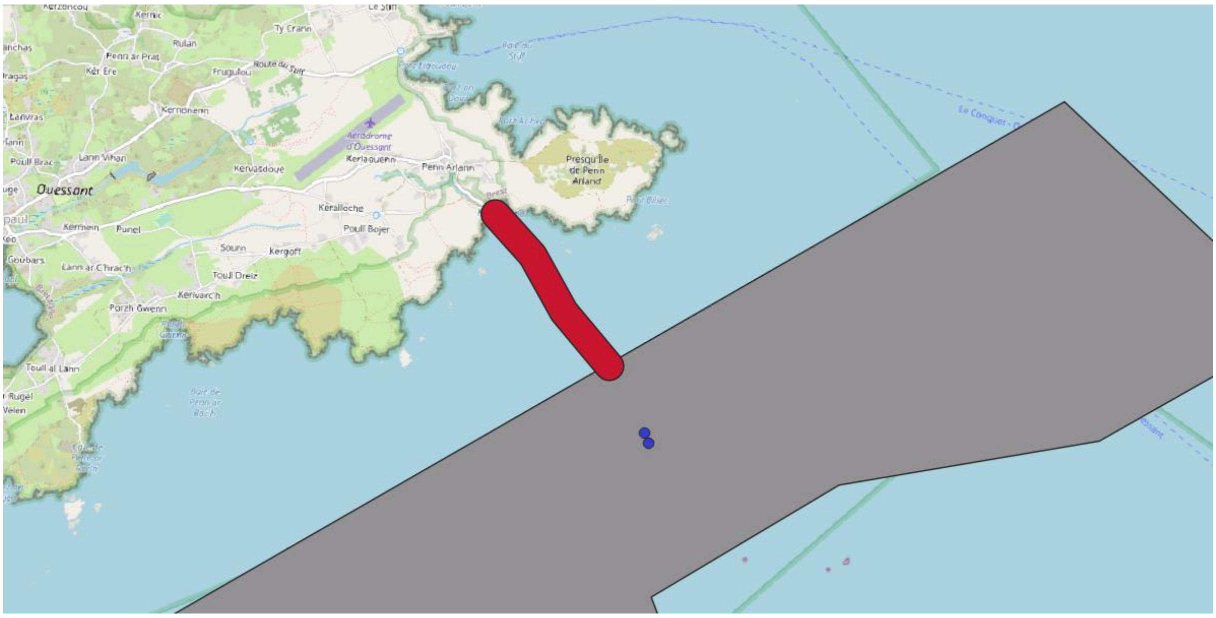


FIGURE 5.3 SABELLA VS5.2 PROJECT IN THE FROMVEUR STRAIGHT IN BRITTANY (FRANCE)

5.2.5 VS5.2 RESULTS

In this section, results obtained by SABELLA from running Validation Scenario 5.2 within the DTOceanPlus suite of tools are provided. For confidentiality reasons, some key metrics have been selected, compared to the real case study values, and expressed under a relative difference form, along with explanatory comments.

The following formula is used to calculate the relative difference:

$$Relative\ Difference\ (\%) = \frac{Value_{DTOceanPlus} - Value_{SABELLA}}{Value_{SABELLA}}$$

A negative value thus means that the value calculated by DTOceanPlus is inferior to the reference value from SABELLA.

For general remarks from SABELLA on Deployment and Assessment tools functionalities and user-friendliness, reference is made to Section 6.3.5.

5.2.5.1 SITE CHARACTERISATION

The Fromveur Straight was partially defined using SABELLA proprietary data, formatted to match the Site Characterization module requirements. The Site Characterization module was relatively easy to use, and the database already included makes it convenient to create a site for which data is not available to the user (bathymetry, seabed type and roughness and endangered species).

The Array Landing Point is located on the Ushant Island in Brittany (France); see red line in Figure 5.4.

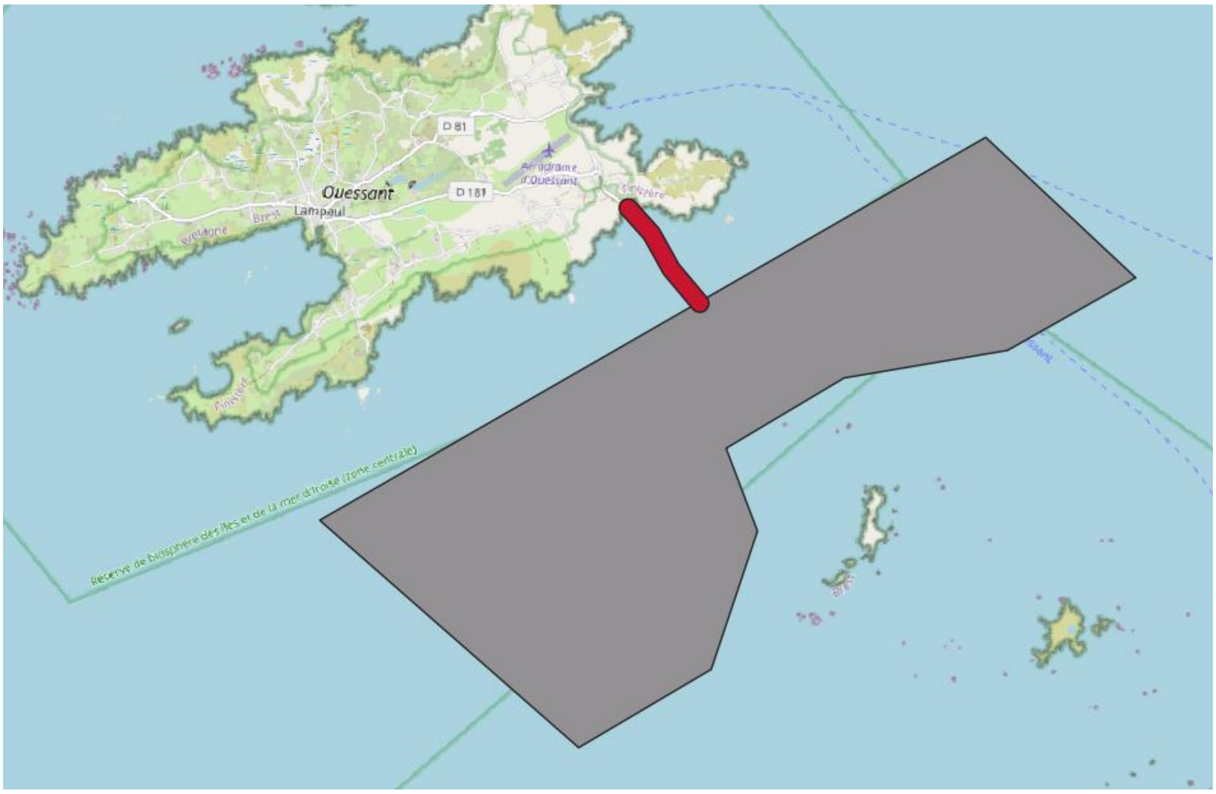


FIGURE 5.4 SABELLA VS5.2 LEASE (GREY) AND CORRIDOR (RED) AREAS IN THE FROMVEUR STRAIGHT IN BRITTANY (FRANCE)

5.2.5.2 MACHINE CHARACTERISATION

SABELLA D15-500 characteristics were conveniently modelled with the Machine Characterization Design tool. However, we suggest completing the turbine modelling with a tab dedicated to the definition of the control strategy, in the form of a tidal flow speed vs turbine rotational speed table.

5.2.5.3 ENERGY CAPTURE

The Energy Capture module was easy to use in integrated mode, except that it could be explicitly mentioned that the coordinate system used for the location of the devices is the UTM 30.

We observed a 6.5% overestimation of captured energy by this module compared to the real case study.

5.2.5.4 ENERGY TRANSFORMATION

SABELLA was able to run the Energy Transformation module at complexity 3. Except for the definition of the control strategy of the turbine, which has been extensively discussed with the module developers and for which propositions were made in the Validation Task Evaluation Form, SABELLA was able to model the technology properly.

In Table 5.3, a comparison between the real case study established by SABELLA and results obtained with the Energy Transformation module is provided:

TABLE 5.3 EVALUATION OF RESULTS FROM ENERGY TRANSFORMATION IN VS5.2

Category		Relative difference (%)	Comments
Design - Weight of the components		-61	Weight is 2.6 times higher in SABELLA estimations for the corresponding components
Design - Bill of Materials	Grid conditioning cost	-80	The cost for the grid conditioning is five times higher in SABELLA turbines. A transformator was not included in the ED module, though there is one in SABELLA turbines. Allowing to add extra costs and weights for components that are not represented in the ET module would be useful.
	Drivetrain cost	-	No model was implemented for direct-drive transmission; thus, the cost for the drivetrain was null.
	Generator cost	0	Values for the PMSG were entered via the catalogue, thus matching the real cost
Assessment - Energy	Captured Energy	6.5	Calculated in EC. Regarding the assumptions made in the site characterization, this difference is acceptable
	Mechanical Energy	7	There should be no difference between captured and mechanical energy, as no loss due to friction is accounted for
	Electrical Energy	-30	This difference is partly explained by the poor modelling of the turbine operation by the Energy Transformation module. Suggestions to add a 'velocity vs omega' table to the Cp/Ct definition section in MC would significantly improve control definition in DTOceanPlus. Another explanation is the complexity to represent generator characteristics with the ET module.

Category		Relative difference (%)	Comments
	Grid Conditioned Energy	-28	A large part of this difference is explained by the discrepancy between DTOceanPlus and the real case study for Electrical Energy
Additional calculations from SABELLA	Captured Energy to Mechanical Energy efficiency	0.5	
	Mechanical Energy to Electrical Energy efficiency	-35	This difference is partly explained by the poor modelling of the turbine operation by the Energy Transformation module. Suggestions to add a 'velocity vs omega' table to the Cp/Ct definition section in MC would significantly improve control definition in DTOceanPlus. Another explanation is the complexity to represent generator characteristics with the ET module.
	Electrical Energy to Grid Conditioned Energy efficiency	2.8	
Assessment - Economics	Cost of the components	-58	

5.2.5.5 ENERGY DELIVERY

The Energy Delivery could be run at complexity 3, and SABELLA faced no major issue with VS5.2. However, we had to adjust some values related to the voltage to match with values proposed by the dropdown menus of the ED module.

In Table 5.4, a comparison between the real case study established by SABELLA and results obtained with the Energy Delivery module is provided:

TABLE 5.4 EVALUATION OF RESULTS FROM ENERGY DELIVERY IN VS5.2

Category	Relative difference (%)	Comments
Annual energy yield	-27	A large part of this difference is explained by the discrepancy between DTOceanPlus and the real case study for Electrical Energy in the Energy Transmission module
Annual losses	-65	
Annual efficiency	1.7	
Total cost (electrical)	-31	This item includes the onshore infrastructure costs. Without the onshore infrastructure contribution, the costs from the Energy Delivery module would be twice the costs from the real case study

Category	Relative difference (%)	Comments
Cost of energy (electrical)	-4.6	The cost and the energy yield are underestimated by the same amount, leading to a cost of energy close to the real case study
Transmission network design - Total length of export cable	3.5	
Bill Of Material Summary - Transmission network costs	-20	
Static cables - Installation cost (proxy)	-8	

5.2.5.6 STATION KEEPING

The order of magnitude for both loads and stability-related results seems correct.

5.2.5.7 LOGISTICS AND MARINE OPERATIONS

The terminal selected by the LMO module was Portland for Installation and Decommissioning Operations. In the current organisation at SABELLA, turbines are manufactured in Brest (France), which is closer to our offices. We may study Portland as an alternative for the upcoming projects. Nonetheless, this would be appreciated to have more flexibility on the terminal that the LMO module uses.

We noticed a significant difference between what was described in the real case study O&M plan and what was proposed by the LMO module. We would have been really interested in having a much more detailed description of sequences of onshore and offshore operations. These results are visible on the "Export Full Study" page but in a json file format, from which information is hard to extract. For this reason, no relevant comment could be made on cost and duration estimates for unitary operations, and only high-level comparisons could be made.

As stated previously, unrealistic time series were defined for the wave climate. Thus, Waiting on Weather-related calculations were affected.

In Table 5.5, a comparison between the real case study established by SABELLA and results obtained with the Logistics and Marine Operations module is provided:

TABLE 5.5 EVALUATION OF RESULTS FROM LOGISTICS AND MARINE OPERATIONS IN VS5.2

Category		Relative difference (%)	Comments
Installation solution	Foundation - Total duration	397	Installation time required is 5 times higher than estimated by SABELLA
	Foundation - Total costs	18	
	Cable - Total duration	56	Duration is 1.5x higher than estimated by SABELLA
	Cable - Total costs	-54	
	Device - Total duration	155	Duration is 3x higher than estimated by SABELLA
	Device - Total costs	-72	Total costs for device + support structure installations are underestimated by a factor of 3. LMO misses additional costs related to project management and preliminary studies
Maintenance solution	Inspection total costs	171	
	Inspection total duration	171	
	Number of operations	100	Half of the preventive maintenance operations were not planned by SABELLA. We did not consider using the catalogues to adjust the frequency before running LMO. This would have made the Maintenance operations generated by LMO much closer to the reality.
Decommissioning solution	Foundation - Total duration	378	Duration is overestimated by a factor of 4.5
	Foundation - Total costs	18	
	Device - Total duration	145	Duration is overestimated by a factor of 2.5
	Device - Total costs	-72	Costs are underestimated by a factor of 3.5

The Logistics and Marine Operations tool is definitely one of the more interesting modules of the full DTOceanPlus suite from SABELLA perspective.

However, we think it is important to have more flexibility in the definition of operations. In VS5.2, during the installation and decommissioning phases, the device and the foundation are installed in a single operation, with the device being laid on the support structure. However, it is only possible to remove the nacelle from the support structure during maintenance operations. Accounting for these multiple possibilities would add further value to the tool.

5.2.5.8 SYSTEM PERFORMANCE AND ENERGY YIELD (SPEY)

The System Performance and Energy Yield Assessment tool was run at complexity level 3. In Table 5.6, a comparison between the real case study established by SABELLA and results obtained with the SPEY module is provided:

TABLE 5.6 EVALUATION OF RESULTS FROM SPEY IN VS5.2

Category		Relative difference (%)	Comments
Efficiency	Relative Array Transformed Efficiency	31	
	Relative Array Delivered Efficiency	1.8	
Energy Production	Array Lifetime Gross Energy	-14	A large part of this difference is explained by the discrepancy between DTOceanPlus and the real case study for Electrical Energy in the Energy Transmission module
	Array Lifetime Lost Energy	-100	The meaning of this metric is not clear, so we considered this was the loss due to devices unavailability. This is 250 times higher in the real case study than calculated in the SPEY module.
	Array Lifetime Net Energy	-11	A large part of this difference is explained by the discrepancy between DTOceanPlus and the real case study for Electrical Energy in the Energy Transmission module

5.2.5.9 SYSTEM LIFETIME COSTS

The System Lifetime Costs module was run, and a comparison between the reference case study and results from SLC was made for some key metrics (see Table 5.7). Calculations related to ACE (Average Climate Capture Width/ Characteristic Capital Expenditure) have not been done, as this metric is not used in the tidal industry.

TABLE 5.7 EVALUATION OF RESULTS FROM SLC IN VS5.2

Category	Relative difference (%)
Economic Metrics - LCOE	-14
Economic Metrics - CAPEX	-27
Economic Metrics - Cost equipment	-31
Economic Metrics - Cost installation	11
Economic Metrics - Total OPEX	-9.6

5.2.5.10 RAMS

Due to issues encountered in each RAMS module and lack of time to solve them, using the RAMS Assessment tool within the project timeline has not been possible.

5.2.5.11 ENVIRONMENTAL AND SOCIAL ACCEPTANCE

Due to issues with the ESA modules (Device Info and Electrical Info GUI empty), and lack of time to solve these issues, it has not been possible to use the ESA Assessment tool within the project timeline.

5.2.5.12 STAGE GATE

We found this module quite user-friendly. However, some limitations emerged, like the unavailability of the Improvement Areas feature, probably due to our inability to run RAMS and ESA.

General comments on Activity checklist

The activity checklist is an interesting feature to help companies see what will need to be achieved to scale up at the start of their activity. We think this tool will be useful when communicating with other stakeholders as it sets a common ground. However, we could not appreciate this specific aspect because we had to set our own thresholds without a third party involvement, thus without having the real-life expectations from project developers for our particular case, for example.

Some specific and minor issues were raised in the Validation Task Evaluation Form, addressing user-friendliness aspects of the Activity Checklist.

General Comments on the Stage Gate Assessment in Applicant Mode

Maybe it could be useful to add a text on the main page to inform the user that he can assess their technology against a single Stage Gate, but he has the possibility to do more if needed. Furthermore, quantitative questions should be more visible to the user, as they are easy to miss.

When quantitative data cannot be fetched from the D&A tools (because the Stage Gate tool is run in standalone mode or some modules have not run), this should be explicitly explained to the user and the blank fields they need to fill should be highlighted.

General Comments on the Improvement Areas functionality

This feature seems really useful for early-stage technology developers, as they will face many hurdles in the product development process. Maybe more advanced technology developers will not find the Improvement Areas as useful because they are already aware of their technology's critical issues.

However, as this tool is expected to be an intermediate between an Assessor and an Applicant, it can raise any concerns or issues and better comprehend the Assessor's challenges the Applicant is currently dealing with.

Results obtained with the Stage Gate tool

Based on the Activity Checklist results, we used the Stage Gate tool to produce a report with relevant information relative to Stage Gate 3-4, which was the most appropriate stage for SABELLA technology readiness.

During the verification and validation processes, we successfully tested the Stage Gate tool both in standalone and integrated mode. The integrated mode is undoubtedly the most interesting way to use the tool, as the process of fetching results from the D&A modules is efficient.

Due to the discrepancy in how Deployment modules calculate production, no exploitable value for the LCOE was extracted at the time of writing, thus limiting our ability to fulfil the design objectives for VS5.2. However, once this issue is resolved, the Stage Gate tool will easily allow technology developers to visualise the progress still to be done to move to the next Stage.

We were considering our technology to be at Stage 3 beforehand, linking to the IEA-OES standardized framework. This was confirmed by the Stage Gate tool, but results emphasised the need to spend more resources on some activities, e.g. onshore testing, particularly via dedicated rigs adapted to the study of accelerated life testing of the PTO.

The Areas of Improvement feature could not be run at the time of writing. Therefore, no link could be made with the SI tool.

6. VS6 DEPLOYMENT DESIGN TOOLS WITH TIDAL ARRAYS

Validation Scenario 6 is representative of a **Tidal Energy Technology**, using the **Deployment Design Tools** at **Array Level**. Nova, Orbital and Sabella considered three sub-scenarios.

The scenario objectives were

- To carry out a third party 'validation' of new array projects at various sites, but also to assess how their device/technology works in an array compared against an individual device & provide evidence for marketing/investment
- Ensuring the functionality of floating tidal array projects and ensure that what's being validated is adjusted to floating
- Provide a well validated tool for the next five years

6.1 VS6.1 NOVA

6.1.1 VS6.1 DESIGN OBJECTIVES

To carry out a 'validation' of a (new) array deployment at a proposed tidal site to provide third party evidence of performance to corroborate investment cases.

6.1.2 VS6.1 USE CASES AND USER STORY

The Nova use case for validation was to utilise our well-proven M100 tidal turbines and deploy a large array of 10-50 turbines at Nova's operational tidal site in Bluemull Sound, Shetland Islands, Scotland. The Shetland Tidal Array already consists of 4 turbines and has been operational since 2016, therefore providing an excellent real-life data-driven validation opportunity.

Due to integrated deployment tool limitations, the use case validated was for a 4-turbine array of M100 turbines at a new site: Raz Blanchard. This provided a good indirect comparison with the known performance of the Shetland Tidal Array, the world's first in-sea tidal array.

6.1.3 VS6.1 DTOCEANPLUS TOOLS SELECTION

For VS6.1, only the Main Module (MM), Deployment Design tools (SC, MC, EC, ET, ED, SK, LMO) and catalogues (CM) were tested, as shown in Table 6.1. Although it was not possible to test the Logistics and Marine Operations tool at complexity 3, the functionalities utilising our amended VS6.1 were demonstrated and discussed in-depth on a call with WavEC and all three tidal developers.

TABLE 6.1 TOOLS AND COMPLEXITY LEVELS TESTED IN VS6.1

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)	✓	✓	✓ Demonstrated by WavEC

6.1.4 VS6.1 INPUT DATA DESCRIPTION

Due to integrated software issues, it was not possible to use data for the Nova Bluemull Sound deployment in the Site Characterisation tool; therefore, one of the built-in example sites was tested. This was the medium wave/high current resource, located at Raz Blanchard, France, similar to other sites Nova is very familiar with and provided a good validation scenario. Nova hopes to undertake further work with the University of Edinburgh under the EnFAIT project[1] for VS6.1 at Bluemull Sound (shown below) over the following year.

FIGURE 6.1 LOCATION OF BLUEMULL SOUND DEPLOYMENT SITE

[1] Enabling Future Arrays in Tidal, H2020 Grant Agreement № 745862, https://www.enfait.eu/.

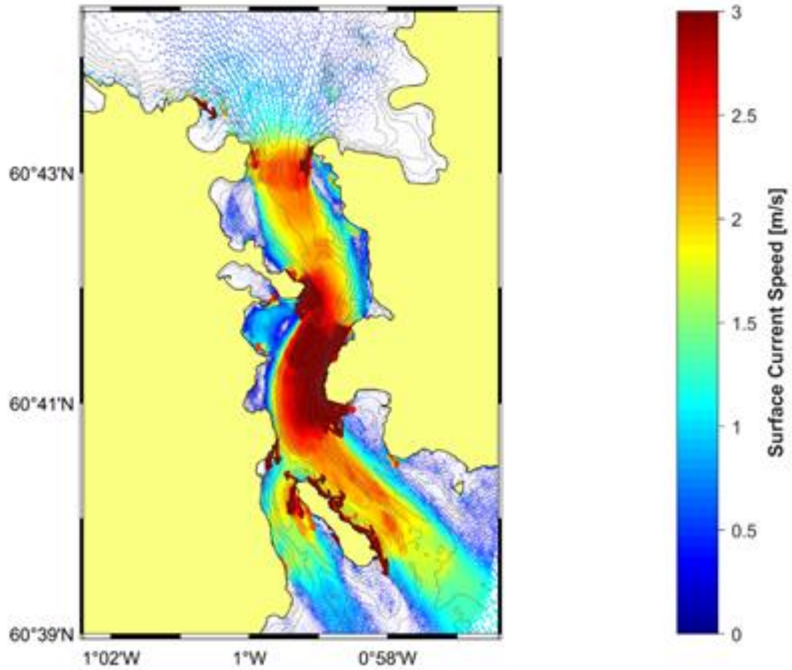


FIGURE 6.2 MODELLED SURFACE CURRENT SPEED AT BLUEMULL SOUND DEPLOYMENT SITE

Dimensions and electromechanical properties of the well-proven Nova M100D tidal turbine were used in the modules as far as possible.

Technical Specification – Nova's M100-D Tidal Turbine			
Rated Capacity	100 kW	Rotor Speed	10 to 27 rpm
Design Life	20 Years	Tidal Speed Range	0.5 – 6.0 m/s
Blade Diameter	8.5 metres	Tidal Speed for Rated Power	2.0 m/s

*Typical configuration: can be adjusted to optimise performance at a particular site

FIGURE 6.3 PHOTOGRAPH AND TECHNICAL SPECIFICATIONS OF NOVA M100-D TIDAL TURBINE

Where VS6.1 input parameter values utilised differed from those provided in the catalogues, these were updated to reflect reality, e.g. the use of multicat vessels (see photo below), cable parameters, etc.

FIGURE 6.4 DEPLOYMENT OF A NOVA M100-D TIDAL TURBINE FROM MULTI-CAT VESSEL

6.1.5 VS6.1 RESULTS

The results of VS6.1 are presented in this section, covering first overall comments, then module-specific comments in subsequent subsections.

Whilst the Deployment tool integration, bug-fixing, and installation issues have taken up vast amounts of Nova time even after the initial integrated software was delivered mid-July, it really feels there is something of utility appearing. We hope to undertake a full further Deployment tool validation of VS6.1 with UoE under the EnFAIT project should the integrated software continue development to a stable tool.

In terms of exporting/post-processing results, Nova would likely only use the 'third party' DTOceanPlus results for comparison purposes with inhouse Nova tools, so results are sufficient, and no further post-processing or direct export is currently required.

6.1.5.1 MAIN MODULE

The advantages are clear in that the use of studies and entities swiftly allows straight forward comparison of the advantages and limitations of various design alternatives. However, as previously mentioned, there were real issues with integrated modules working together, particularly under higher complexity levels.

The ability to 'branch' projects is a powerful functionality allowing sensitivity checking of various scenarios.

6.1.5.2 CATALOGUES

The catalogues are easy to use (or update) flexible means of inputting and accessing relevant data. The ED and LMO catalogues were utilised and edited to reflect better the likely components or vessels Nova would use to deliver an array of tidal turbines of this scale.

6.1.5.3 SITE CHARACTERISATION

Due to software issues, we were unable to input Bluemull Sound data at the higher complexity levels. The example test case data for Raz Blanchard worked well and captured sufficient data for our needs.

Name of the Entity : Nova test 3_sc

Overview

Longitude : -2.02 ° **Latitude :** 49.72 °

Overview of meteocean conditions

Variable / RP	Min	Mean	Max	Std
Waves Hs [m]	0.07	1.32	7.21	0.76
Currents Mag [m/s]	0.11	1.43	3.33	0.77
Winds Mag10 [m/s]	0	8.13	27.59	3.85
Water Levels WLEV [m from MSL]	47.15	47.77	50.18	0.8

FIGURE 6.5 OVERVIEW OF SITE CONDITIONS USED AT BUILT-IN RAZ BLANCHARD SITE, USED TO REPRESENT BLUEMULL SOUND DEPLOYMENT SITE

The integrated software often had issues with low-level project details, as noted in our online feedback (e.g. snapping of close together points etc.)

The GUI was nice to use and understand, while the figures returned seem accurate and the maps are clear.

Currents

Magnitude

Variable name	Minimum	Maximum	Mean	Median	STD
Mag	0.11	3.33	1.43	1.4	0.77
Flux	0.62	18987.93	2868.66	1408.41	3541.2

EJPD MAG-THETA

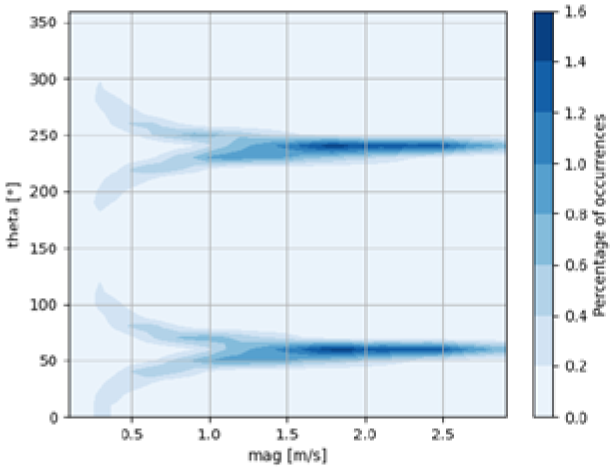


FIGURE 6.6 OUTPUT FROM SITE CHARACTERISATION SHOWING TIDAL RESOURCE

The co-ordinated display of information could be improved, e.g. rather than separately displayed maps (see below) with differing visual scales, layered maps as in a typical Geographical Information System (turbine locations on top of tidal resource, bathymetry etc.) would allow users swift vis ual error checking on expected outputs.

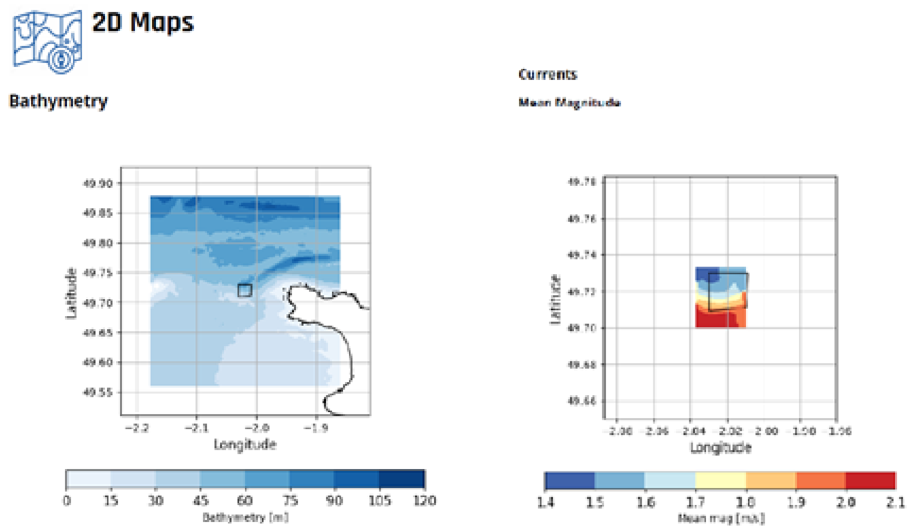


FIGURE 6.7 OUTPUT FROM SITE CHARACTERISATION SHOWN ON SEPARATE PLOTS RATHER THAN COMBINED LAYERS

6.1.5.4 MACHINE CHARACTERISATION

Better information to explain requirements would be beneficial, e.g. bubbles/hover-overs against input definitions in the tool. For example, 'Dimension' definitions would be beneficial to help the user to understand more fully. There is some ambiguity as to how the inputs are used and their importance to the calculation.

6.1.5.5 ENERGY CAPTURE

The GUI and maps allow clear and accurate input of the turbine positional data see Figure 6.8. The data for the M100-D was entered, and the calculated AEP is as would be expected, see Figure 6.9. However, it is not immediately clear what the 'Site Condition Summary' denotes, see Figure 6.10.

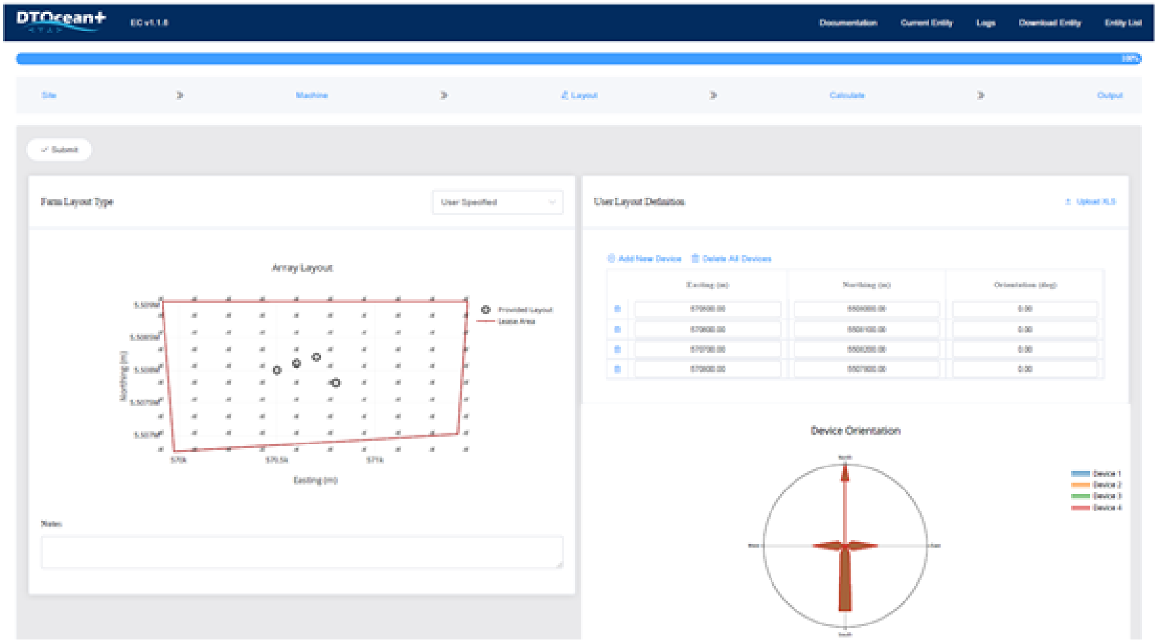


FIGURE 6.8 INPUT OF REPRESENTATIVE ARRAY TO ENERGY CAPTURE

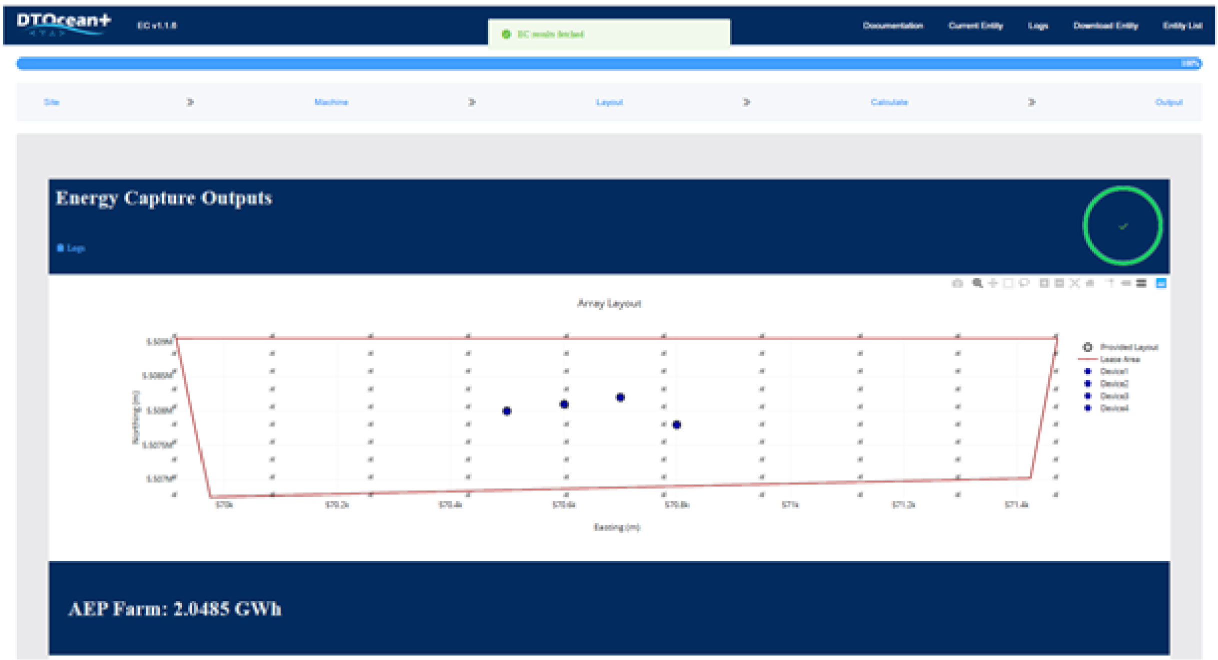


FIGURE 6.9 OUTPUT FROM ENERGY CAPTURE FOR REPRESENTATIVE ARRAY

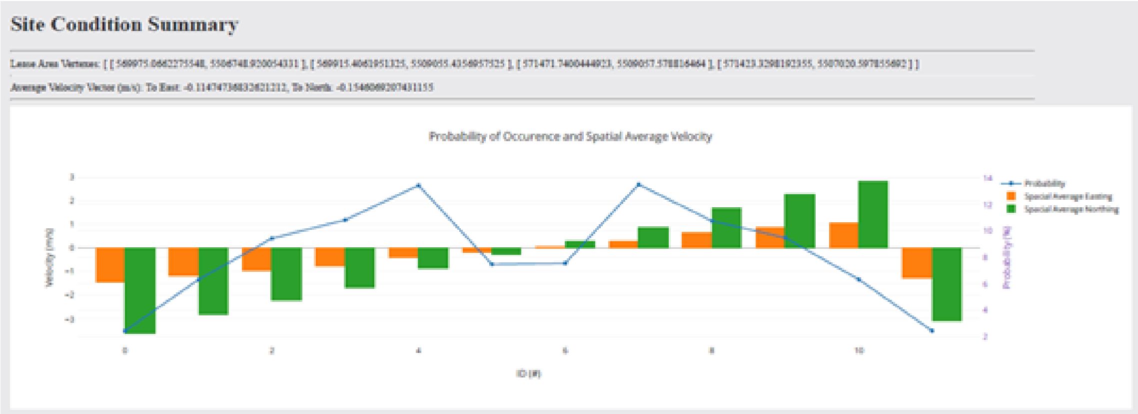


FIGURE 6.10 ENERGY CAPTURE "SITE CONDITIONS SUMMARY"

6.1.5.6 ENERGY TRANSFORMATION

The Nova M100D input data was successfully input to the ET module with the following qualifications:

- In terms of input PMSG efficiencies – perhaps best to use a normal load-efficiency curve?
- There seems to be a lot of input data that may not be required unless the ET module is undertaking a very detailed design, e.g. machine reactances? (Unable to verify the validity of such inputs as higher complexity level 3 not run successfully.)

This module was a little harder to validate as we could not verify higher complexity level scenarios due to software issues and had difficulty deciphering from the GUI-level information where any calculation error had emanated from, e.g.:

- The initial results returned contained massive (unrealistic) losses and no transparency to determine why the calculation was incorrect. Not sure if it was the ET module or another, but energy to the grid (MWh) returned was initially tiny compared to what would be expected. This seemed to be fixed for our final validation attempt, but more validation testing was required.
- There would seem to be more power after mechanical efficiencies are accounted for? See screenshot of returned textual results, Figure 6.11.

ET_devices_outputs (complexity 2).json

```
    },
    "Dev_P_Capt": {
      "description": "Captured power per sea state",
      "label": "Captured Power per sea state",
      "unit": "kW",
      "value": {
        "Power": [
          0,
          372.56,
          194.3,
          86.72,
          11.01,
          0,
          0,
          8.07,
          77.25,
          183.08,
          342.27,
          475.22
        ],
```

ET_devices_outputs (complexity 2).json

```
    },
    "Dev_P_Mech": {
      "description": "Mechanical power per sea state",
      "label": "Mechanical Power per sea state",
      "unit": "kW",
      "value": {
        "Power": [
          0,
          376.47,
          196.34,
          87.63,
          11.13,
          0,
          0,
          8.16,
          78.07,
          185,
          345.86,
          480.21
        ],
```


FIGURE 6.11 COMPARISON OF JSON RESULTS FROM ENERGY TRANSFORMATION, SHOWING HIGHER POWER AFTER MECHANICAL TRANSFORMATION STEP (RIGHT)

6.1.5.7 ENERGY DELIVERY

The ED module seemed to return sensible solutions and performance numbers that closely matched expectations for this site. ED catalogue cable parameters relevant and utilised successfully. Costs are not representative but may be easily changed in the catalogue to actuals for improved accuracy.

Additionally, further options for the hub(s) with dry-mate connectors could be useful.

FIGURE 6.12 OUTPUT OF ENERGY DELIVERY FOR REPRESENTATIVE ARRAY IN VS6.1

6.1.5.8 STATION KEEPING

The SK module GUI has a good clear layout.

Our previous design iterations of the standalone tool with FEM means the software now nicely takes care of gravity foundations for tidal developers and returns reasonable results in line with expectations, i.e. mass required to stop overturning or slippage for our M100D turbines.

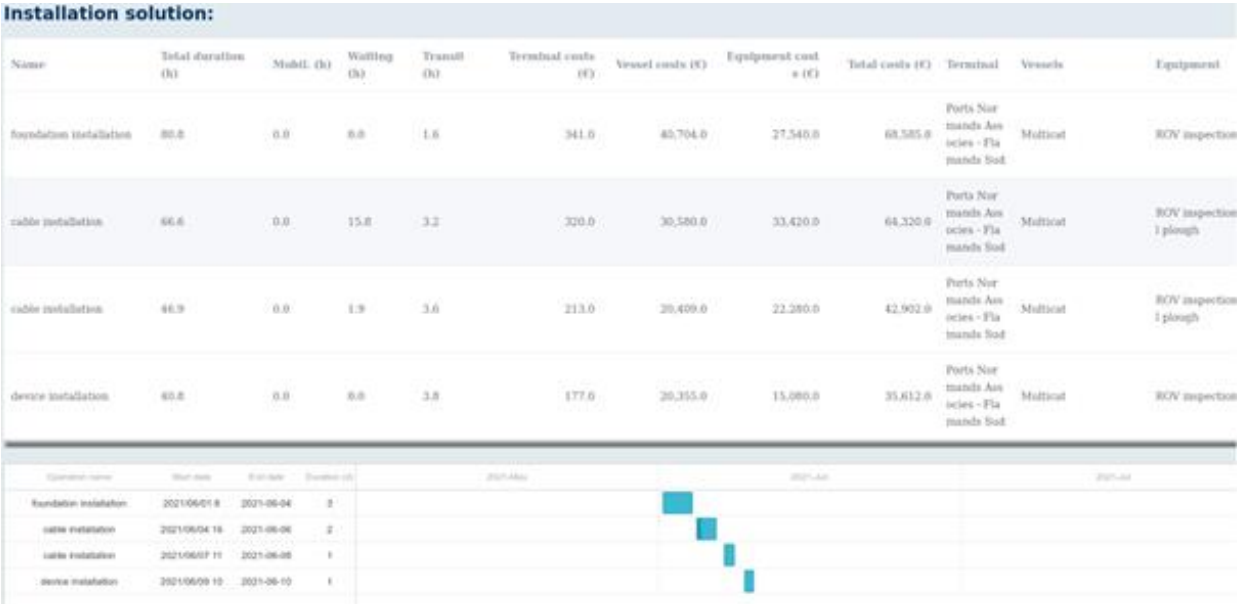
In future, it would be useful if the tool undertook further iterations of the initial design to account for the self-induced drag of each calculated foundation design.

6.1.5.9 LOGISTICS AND MARINE OPERATIONS

The LMO catalogue seems comprehensive; details are accurate and easily adapted to a user's requirements.

The results obtained from VS6.1 indicate a few improvements to the LMO toolset:

- It would be good to be able to force a maintenance rate (e.g. x0.5 p.a.) as MTBF from another module (ET?) seemed to result in ridiculously high intervention rates initially?
- An ability to remove divers and ROVs should be added as neither are required to deploy Nova turbines.
- All cables require decommissioning, and this must be included as standard.
- Differing operations will have certain time windows (between tidal velocity limits during 'slacks') to achieve. At some sites, this may mean operations must be spread across certain predictable tidal conditions (e.g. neaps). The software should be adapted to allow for this.
- All facets of Nova deployment and recovery are designed to utilise lower cost multicat vessels – this leads to an actual estimated cost an order of magnitude lower than that initially calculated by the tool.
- Additionally, the time actually taken to perform the offshore operations is likely somewhat lower (30%) than that calculated.
- Overall, even after modifying details in the catalogue, the costs calculated are higher than those expected in real life. This is likely to do with the scheduling performed, which may be further investigated in future.



Installation solution:

Name	Total duration (h)	Mobil. (h)	Waiting (h)	Transit (h)	Terminal costs (€)	Vessel costs (€)	Equipment costs (€)	Total costs (€)	Terminal	Vessels	Equipment
foundation installation	80.8	0.0	0.0	1.6	341.0	40,704.0	27,540.0	68,585.0	Ports Normands Associes - Flamands Sud	Multicat	ROV inspection
cable installation	66.6	0.0	15.8	3.2	320.0	30,580.0	33,420.0	64,320.0	Ports Normands Associes - Flamands Sud	Multicat	ROV inspection l plough
cable installation	46.9	0.0	1.9	3.6	213.0	20,409.0	22,280.0	42,902.0	Ports Normands Associes - Flamands Sud	Multicat	ROV inspection l plough
device installation	40.8	0.0	0.0	3.8	177.0	20,355.0	15,080.0	35,612.0	Ports Normands Associes - Flamands Sud	Multicat	ROV inspection

Operation name	Start date	End date	Duration (d)
foundation installation	2021/06/01 8	2021-06-04	3
cable installation	2021/06/04 16	2021-06-06	2
cable installation	2021/06/07 11	2021-06-08	1
device installation	2021/06/09 10	2021-06-10	1

FIGURE 6.13 OUTPUT FROM LMO SHOWING INSTALLATION SOLUTION CALCULATED

6.2 VS6.2 ORBITAL

6.2.1 VS6.2 DESIGN OBJECTIVES

To validate potential scaling up of the current Orbital O2 drivetrain to be deployed at EMEC berth 5. Results of which will be used to inform business decisions with regard to future projects.

6.2.2 VS6.2 USE CASES AND USER STORY

The original Orbital case for the validation was to take the current orbital O2 drivetrain (Figure 6.14) and scale-up rotor diameter, from the current 20m, in set increments to find an optimal design for deployment at EMEC berth 5. The O2 has recently been deployed at berth 5, and is currently undergoing a staged commissioning program; therefore, full operational data is not available for comparison in the validation cases. The validation case will therefore have to be carried out against initial design parameters.

Due to the integration issues, it could not carry out the validation against the site at EMEC berth 5; therefore, all work was done at Raz Blanchard.

FIGURE 6.14 ORBITAL O2 DRIVETRAIN RECENTLY DEPLOYED AT EMEC

6.2.3 VS6.2 DTOCEANPLUS TOOLS SELECTION

For VS6.2, only the Main Module (MM), Deployment Design tools (SC, MC, EC, ET, ED, LMO) and catalogues (CM) were tested, as shown in Table 6.2. Note that although it was not possible to test the Logistics and Marine Operations tool at complexity 3, the functionalities were demonstrated and discussed on a call with WavEC and the three tidal developers. Attempts were made to validate the Station Keeping tool, but it was unable to load the data in from previous tools correctly and thus unable to be processed, so although no results were generated, the use of the tool can be commented on.

TABLE 6.2 DEPLOYMENT TOOLS AND COMPLEXITY LEVELS TESTED IN VS6.1

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)	Partially ✓		
Logistics and Marine Operations (LMO)			Demonstrated by WavEC

6.2.4 VS6.2 INPUT DATA DESCRIPTION

With the software issues, it was not possible to use Orbital's data for the EMEC berth 5 in the site characterisation tool. So for the validation cases ran, the database example sites in the tool were used. For complexity levels 1 and 2, this was the Raz Blanchard site with the medium wave/high current resource. Although not exact to the conditions at EMEC berth5 5, it is similar and in line with other sites, Orbital are exploring.

Machine characterisation data was input with accurate data to represent the Orbital O2 turbine, and for the validation cases, this data was altered slightly to represent the potential for drivetrain scaling, such as a larger rotor diameter. Baseline technical specifications for the orbital O2 are shown in Table 6.3

TABLE 6.3 TECHNICAL SPECIFICATION FOR THE ORBITAL O2 TURBINE

Parameter	Value
Rated capactiy	2,000kW
Rated Tidal Speed	2.5m/s
Rotor Diameter	20m
Tidal speed range	0.5m/s – 4m/s
Design life	25 Years

6.2.5 VS6.2 RESULTS

The results of VS6.2 are presented in this section, covering first overall comments, then module-specific comments in subsequent subsections.

Through a number of factors, Orbital has been unable to execute a validation program as originally intended. Once the suite of tools was delivered in mid-July, a limit on personnel availability meant that testing could only commence from mid-August. In this time, good progress has been made. Initially, the main progress was mainly with installation issues and attempts at debugging, but once completed, the tools could be run to a lesser extent than hoped. At the time of report writing, Orbital has yet to fully run through the full set of tools due to a variety of bugs still to be solved. But there are still plans to continue testing the tools going forward and feedback as much as possible to continue developing the tools.

Considering the current development state of the tools, Orbital are unlikely to use the DTOceanPlus results in isolation to make design decisions. It is more likely that the results generated from the tools will be compared with results from Orbitals own in-house work, which has been validated to a high degree of confidence through many years of development. It is hoped that further feedback can still be passed onto the module developers beyond the project end to continue the progression of the development of the tools.

6.2.5.1 MAIN MODULE

The main module is the first stop for using the tools. This has clear advantages as all tools can be organised and accessed from here. The dashboard gives easy access to the documentation which is vital as hold some very important information and instruction for using the tools. This is an incredibly useful addition.

The projects tab is where all projects are defined. It is very clear how to create a new project and then open and edit. The workflow through the study is very clear and easily stepped; as mentioned, there were some issues with the integrated module, particularly with the SK module, which derailed attempts to further work. The option to "fork this study" is a very useful addition and gives a great scope to be able to adjust inputs and compare different scenarios easily without the need to run the whole study again in a different project.

6.2.5.2 CATALOGUES

The catalogues allow you to browse all preloaded inputs that are available; this was incredibly useful when carrying out preliminary testing of the tools to familiarise with the operations. It enables you to check the values of the components or inputs selected, therefore meaning you can compare to the real values required. Although not tested, it also allows the possibility of adding a new item to the catalogue had it not been included originally.

6.2.5.3 SITE CHARACTERISATION

Due to previously mentioned issues, Orbital was unable to input and validate the data for EMEC berth 5. Therefore, Raz Blanchard was used instead. This was deemed a suitable proxy for EMEC berth5 for the validation cases. To achieve this complexity level 2 was selected with wave level medium and current level high, as shown in Figure 6.15.

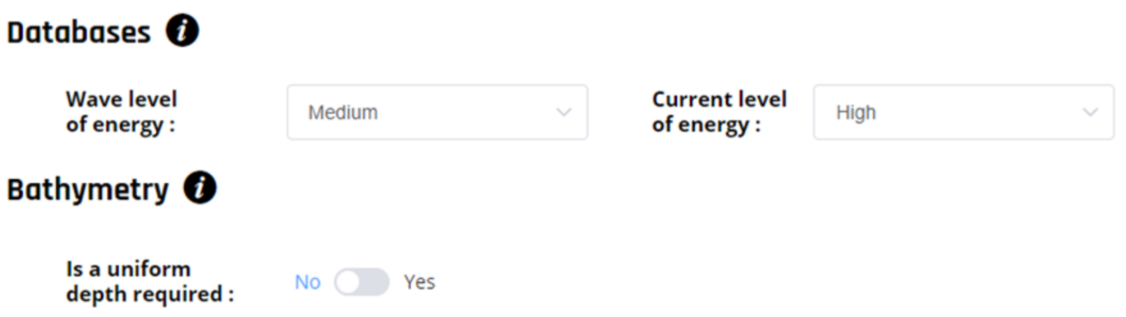


FIGURE 6.15 SELECTION OF EXAMPLE SITE FOR VS6.2

Figure 6.16 shows a snapshot of the results provided. As mentioned above, the site is a suitable proxy for EMEC berth5, the maximum current speed is around 40-50% lower than what we could expect at EMEC, so this will need to be considered when working through the validation cases.

Extreme value of meteocean conditions

Variable / RP	1 year	5 years	10 years	50 years
Waves Hs [m]	5.41	6.55	7.34	7.68
Currents Mag [m/s]	3.3	3.33	3.34	3.34
Winds Mag10 [m/s]	23.41	26.04	27.85	28.64

FIGURE 6.16 EXAMPLE RESULTS SITE USED FOR VS6.2

The plot shown in Figure 6.17 is Orbitals preferred graphical option for displaying tidal resources; it is a good option to have along with the EJPD plot.

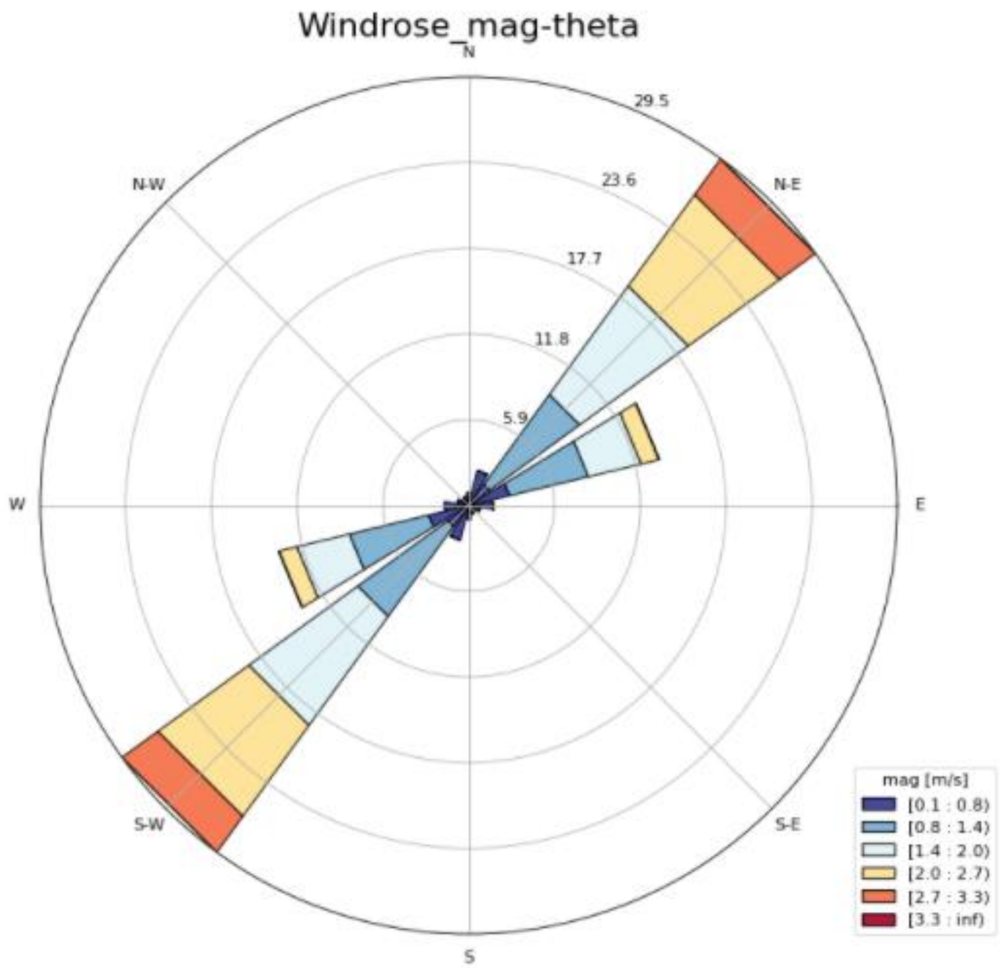


FIGURE 6.17 PLOT SHOWING TIDAL RESOURCE

The tool is very easy to use, and the results are very well presented and easy to understand. The maps are very clear and informative; currently, there is only an option to export to PDF; it would be advantageous if these results could be exported in the UTM coordinate system or DWG/DXF files to import into software such as draftsight.

6.2.5.4 MACHINE CHARACTERISATION

It was easy to input the data with a simple format and workflow through to complete the tool. It would benefit from more descriptive definitions for the inputs and how important they are to the calculation, particularly in the dimensions tab. Some better feedback, possibly with floating bubbles, would be a great addition.

It is a bit of a hindrance that once you lock the definition, it is unable to be edited; I realise the reasoning for this feature, but it can be an annoyance if you have made one little error in the input of data and only notice once locked.

6.2.5.5 ENERGY CAPTURE

As with the other tools, the workflow for inputting the data is very simple and straightforward. Working in integrated mode is fantastic as the tools automatically load in the data from the SC and MC tools. The layout tab offers good options to manually input the positions that give good instant feedback with a very good graphical representation or ask the tool to optimise the layout. Again slightly better feedback on some of the options for optimising input values would be beneficial. Sometimes when calculating the results, the visual percentage indicator on the top bar progresses quickly to 100%. However, the calculating results wheel at the bottom continues as if hanging, some slightly more informative feedback on calculation progress would be better to offer assurance that there is no issue with the calculation or hanging.

The AEP values are within the range we would expect considering the SC data. The probability of occurrence plot is somewhat confusing and not immediately informative of what it is showing.

6.2.5.6 ENERGY TRANSFORMATION

This is the first tool that I thought the workflow could do with a little bit of a clearer definition; it does not have the same progression styled bar along the top. It is good that the SC, MC and EC results are automatically input, although this is not immediately obvious. To indicate that the data has been successfully loaded in an information box appears in the top right portion of the screen. A button as in the EC tool to fetch data from the previous tools might be more beneficial.

The inputs for the energy transformation could do with a little more description to makes sure that values being input are what is required. The workflow down through the table/list of inputs is fairly straightforward and simple to follow.

We had a bit of difficulty validating the module compared to the results expected for the Orbital O2 device. The losses reported from captured energy to mechanical energy to electrical then to the grid are magnitudes higher than expected and found in the real O2, was unable to find any reasoning for this or alter inputs to vary this. Users wonders if this might be due to errors included from previous models or depending on the complexity level being run. Orbital will continue to test and validate the tool beyond the scope of the project.

6.2.5.7 ENERGY DELIVERY

The Energy deliver tool again has a simple workflow that is simple to follow; if it could have a similar workflow to previous tools with a progression bar along the top to make it a little more standard throughout the tools, it would be beneficial. But as is, it still works well. Inputting is very simple and easy to understand what the requirements are with little ambiguity as to what could be input.

Considering the inputs, the results seem sensible. The costs are not particularly in line with what would be expected, but this could easily be rectified by manually altering catalogue values.

Further validation work will again be carried out beyond the scope of the project.

6.2.5.8 STATION KEEPING

As alluded to above, there have been serious issues in attempting to get run and validated. There seemed to be an error with the SK tool not loading results correctly from the previous tools. The layout and workflow of the tool are similar to the previous one in that it has good flow and is easy to use. Beyond that, Orbital are unable to comment on the tool as we were unable to get results.

6.2.5.9 LOGISTICS AND MARINE OPERATIONS

Due to issues with the SK tool, Orbital could not carry out any validation work with the LMO tool. This was unfortunate as it was one of the tools that carried a lot of interest. Without running the tool, the UEDIN were able to facilitate a comprehensive walk-through of the tool with the developer that was highly invaluable and gave a fantastic insight into the tool's use and capabilities, which looked fantastic.

The workflow through the tool looked simple and easy to follow as with previous tools. A few pointers taken from the walkthrough were as follows:

- Ability to specify if divers or ROV's are required for operations as Orbital do not use these in every operation.
- Currently, cable decommissioning is not included, which should be
- Different options for in installation of cable as Orbital does not bury the cable, it is just free sitting on the seabed
- Ability to specify mobilisation and de-mobilisation days as with using local workboats in Orkney is normally very short. The standard values in the tool made the operation times for installation or machine removal considerably longer than predicted.
- The cost of vessels and operations seemed to be a magnitude higher than expected; this is due to Orbital's strategy to minimise the cost of Tidal Energy by using low cost vessels
- Functionality to specify operating in certain tidal conditions would be highly beneficial; the nature of tidal work means that work is only really able to be carried out in neap tides. So a functionality

to be able to include this would make any generated schedule considerably more realistic and more useful.
- The ability to alter or add new vessels to the catalogue might allow reducing these costs

Orbital will again continue to validate this tool out with the project. We feel that this tool is a standout tool of the suite that could be invaluable when planning operations and costing operations.

6.3 VS6.3 SABELLA

6.3.1 VS6.3 DESIGN OBJECTIVES

The Design Objective of VS6.3 is to carry out a third party 'validation' of new array projects at various sites and assess how their device/technology works in an array compared against an individual device & provide evidence for marketing/investment.

6.3.2 VS6.3 USE CASES AND USER STORY

The flow of data to the Deployment and Assessment tools can be seen in Figure below.

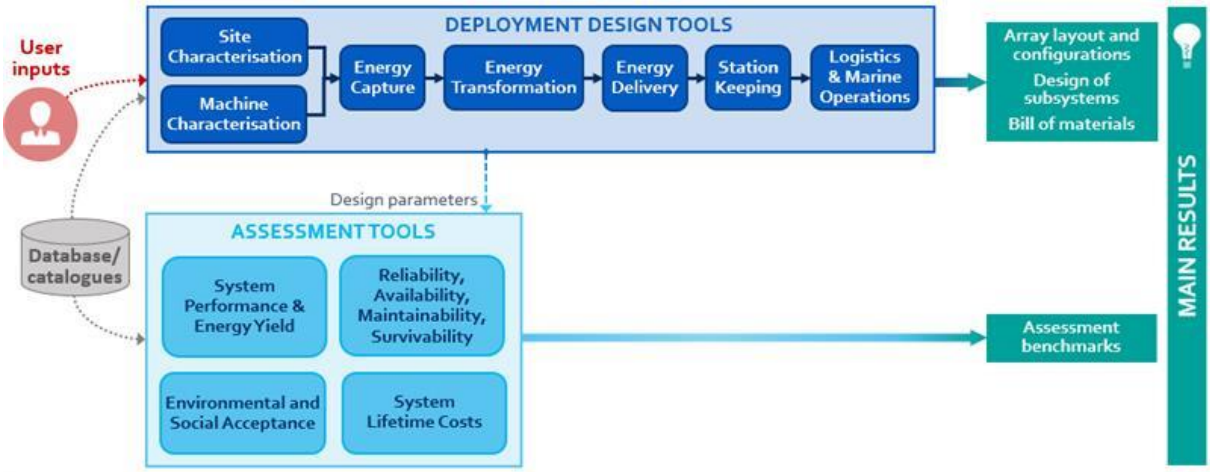


FIGURE 6.18 MAIN FLOW OF INFORMATION BETWEEN MODULES IN VS5.2.

6.3.3 VS6.3 DTOCEANPLUS TOOLS SELECTION

For VS6.3, the Main Module (MM), Deployment Design tools (SC, MC, EC, ET, ED, SK, LMO), Assessment design tools (SPEY, RAMS, SLC, ESA) and catalogues (CM) were tested, as shown in Table 6.4. Note that although it was not possible to test the Logistics and Marine Operations tool at complexity 3, the functionalities were demonstrated and discussed on a call with WavEC and the three tidal developers.

TABLE 6.4 DEPLOYMENT & ASSESSMENT TOOLS AND COMPLEXITY LEVELS TESTED IN VS6.3

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)	Unable to run ESA at complexity 1		
Reliability, Availability, Maintenance, Survivability (RAMS)	Unable to run any of RAMS tools at complexity 1		

6.3.4 VS6.3 INPUT DATA DESCRIPTION

This forward-looking project includes fifty 2 MW D22-2000 SABELLA turbines, with five collection points and a substation. The farm is located in the Fromveur straight in Brittany (France); see Figure 6.19. This site has been partly defined with SABELLA data, using five years timeseries for the velocity field and water height in the lease area. The bathymetry, seabed type, roughness length, and endangered species were defined using the catalogue data provided with the software.

The turbine is a three-bladed, 22m diameter rotor, driving a PMSG through a direct-drive transmission, seeFigure 6.19 SABELLA D22-2000 TIDAL TURBINE. The nacelle is held by a gravity-based metallic support structure.

FIGURE 6.19 SABELLA D22-2000 TIDAL TURBINE

The layout of devices in the Fromveur straight and locations of the collection points (purple circles) and the substation (brown square) is illustrated in Figure 6.20 SABELLA vs6.3 project in the Fromveur straight in Brittany (France)

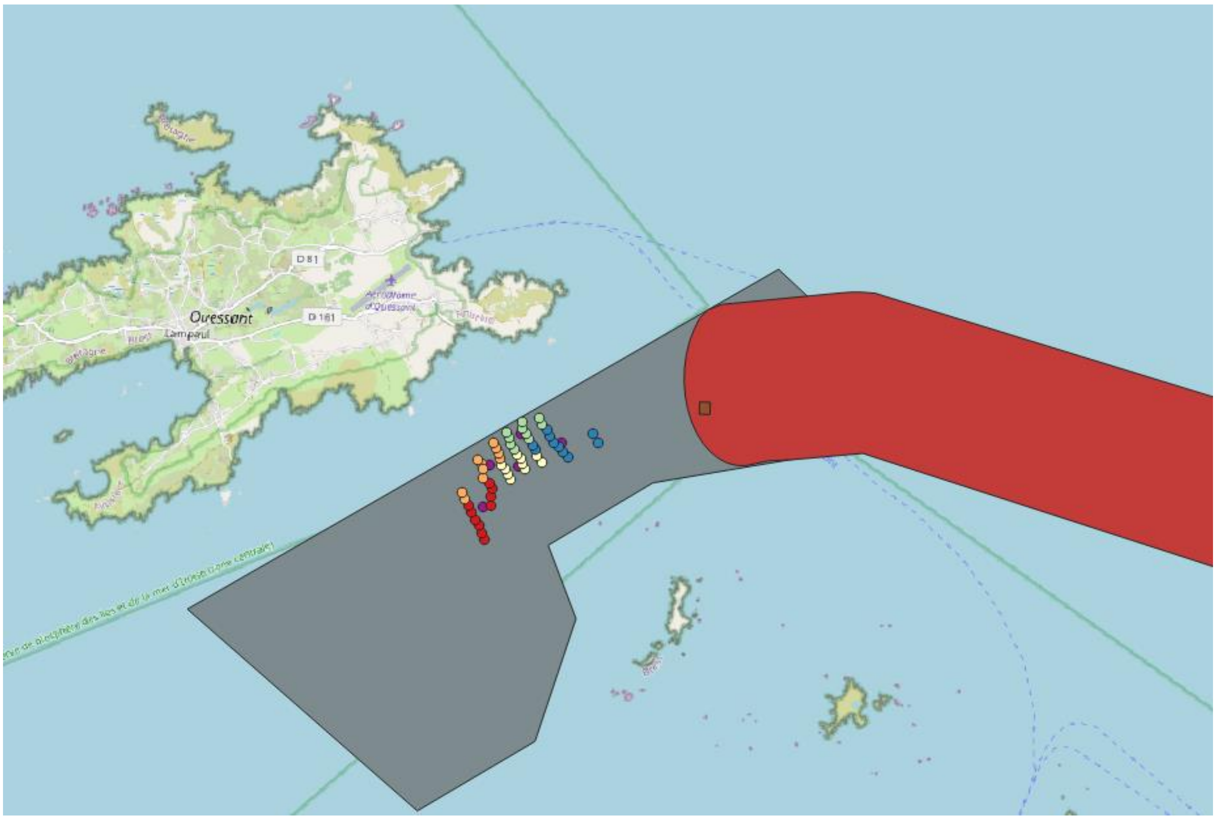


FIGURE 6.20 SABELLA VS6.3 PROJECT IN THE FROMVEUR STRAIGHT IN BRITTANY (FRANCE)

In the reference case study developed by SABELLA, the substation and the export cable from the substation to the array landing point and onshore infrastructures are out of the scope of SABELLA.

An advanced corrective and preventive maintenance plan for this project has been defined by SABELLA.

6.3.5 VS6.3 RESULTS

The results of VS6.3 are presented in this section, covering first overall comments, then module-specific comments in subsequent subsections. For confidentiality issues, some key metrics have been selected, compared to the reference case study values, and expressed under a relative difference form, along with explanatory comments.

The following formula is used to calculate the relative difference:

$$Relative\ Difference\ (\%) = \frac{Value_{DTOceanPlus} - Value_{SABELLA}}{Value_{SABELLA}}$$

A negative value thus means that the value calculated by DTOceanPlus is inferior to the reference value from SABELLA.

SABELLA could successfully use DTOceanPlus to model this forward-looking scenario at full complexity, except for the Logistics and Maintenance Operations module, which had to be run at complexity 1, and RAMS and Environmental and Social Acceptance modules, which we were unable to use due to technical issues.

6.3.5.1 MAIN MODULE

The Main Module was convenient to use, as it allows the user to quickly understand the different possible paths he can go through to achieve the specific goals he needs to fulfil.

We did not check the functionality for the use of studies and entities in comparing the advantages and limitations of various design alternatives. The way studies and entities are created is convenient, except when issues happen with the database, implying issues to create or delete entities, or conflicts between entities numbering sometimes occurring.

6.3.5.2 CATALOGUES

SABELLA views the use of Catalogues as an interesting feature of DTOceanPlus. The libraries are populated with a large amount of data, which will prove very useful for technology developers willing to quickly define a new project, starting from limited information. SABELLA has been mainly using LMO catalogues for VS5.2 and VS6.3.

However, for some of the modules, documentation is currently insufficient to the user to enable him to efficiently use catalogues: parameters and their future use in design tools are opaque, formulas are not really helpful (e.g. in the ET module, a tool could be created so that users provide their data, and requested parameters are calculated unambiguously). Reference to specific sections in the documentation should be made as much as possible.

The formatting of input is sometimes difficult to understand, e.g., the control item for the Energy Transformation module. The format of the Reliability-related inputs necessary to define a PMSG generator was unclear, so we had to use default values. This may have skewed subsequent calculations of Reliability in the Energy Transformation and RAMS modules.

6.3.5.3 SITE CHARACTERISATION

The Fromveur Straight was partially defined using SABELLA proprietary data, formatted to match the Site Characterization module requirements. The Site Characterization module was relatively easy to use, and the database already included makes it convenient to model a new site for which data is not available to the user (bathymetry, seabed type and roughness and endangered species).

The Array Landing Point is located near Trezien in France mainland, see Figure 6.21.

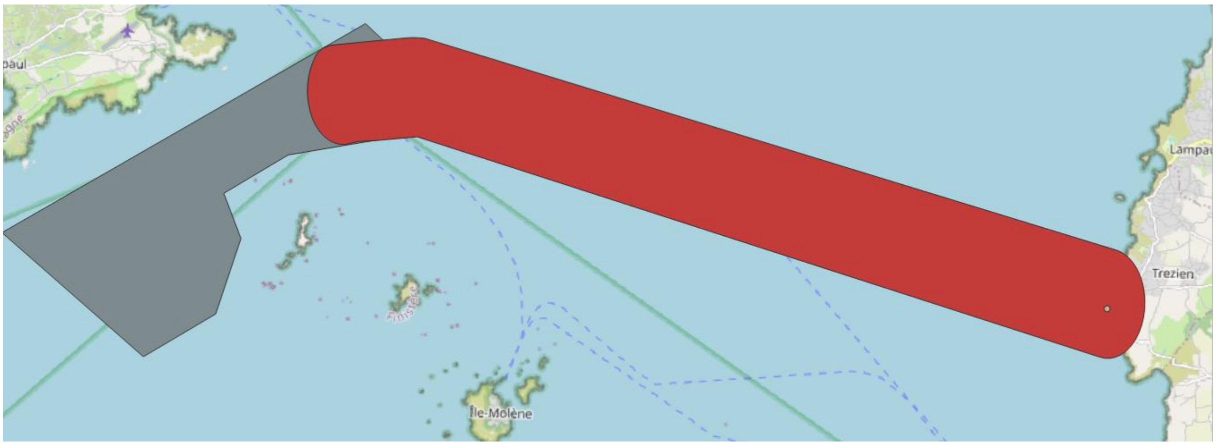


FIGURE 6.21 SABELLA VS6.3 LEASE (GREY) AND CORRIDOR (RED) AREAS IN THE FROMVEUR STRAIGHT IN BRITTANY (FRANCE)

We experienced some issues with the definition of coordinates for the lease and corridor areas. Thus, we recommend that the coordinate system to use, here UTM 30, be explicitly described to the user.

We would have appreciated being able to define current and waves timeseries separately and being provided default timeseries for current and waves if one is not available to the user. Actually, for waves, we had to provide random values created following a particular distribution because we did not have the same timesteps for current and waves datasets and had no possibility to create the requested file in the little time we had. Splitting current and waves and allowing for two different time steps would be an easy way to give the user more flexibility.

Another major issue we faced was related to the definition of flow speed timeseries. Flow speed timeseries are usually defined at hub height or depth-averaged along the water column. When defining time series for the velocity field, the user should be allowed to specify either a hub height velocity field or a depth-averaged velocity field. In this last option, he should be allowed to specify a current profile (type and parameters) and be made aware of the subsequent processing his data will go through for the specific definition he used.

6.3.5.4 MACHINE CHARACTERISATION

The MC module is easy to use, steps are clearly identified, and as for VS5.2, we were able to create a new device with characteristics matching the targeted values.

However, allowing the user to define the operation strategy of the device in the Machine Characterization module seems really important for conventional tidal turbines developers. Adding a flow velocity vs rotational speed table to the Cp/Ct definition section would remove any ambiguity in the way the Energy Transformation module sets the rotational speed for each site condition.

In addition, some data requested by the module were tedious to estimate, as they seem to be WEC-related (dry and wet area/frontal area, draft), and no explanation was available to understand how these data would be used.

6.3.5.5 ENERGY CAPTURE

For the captured energy yield, results were found to be 15% inferior to estimation from the reference case study, with large variability between devices, see Figure 6.22.

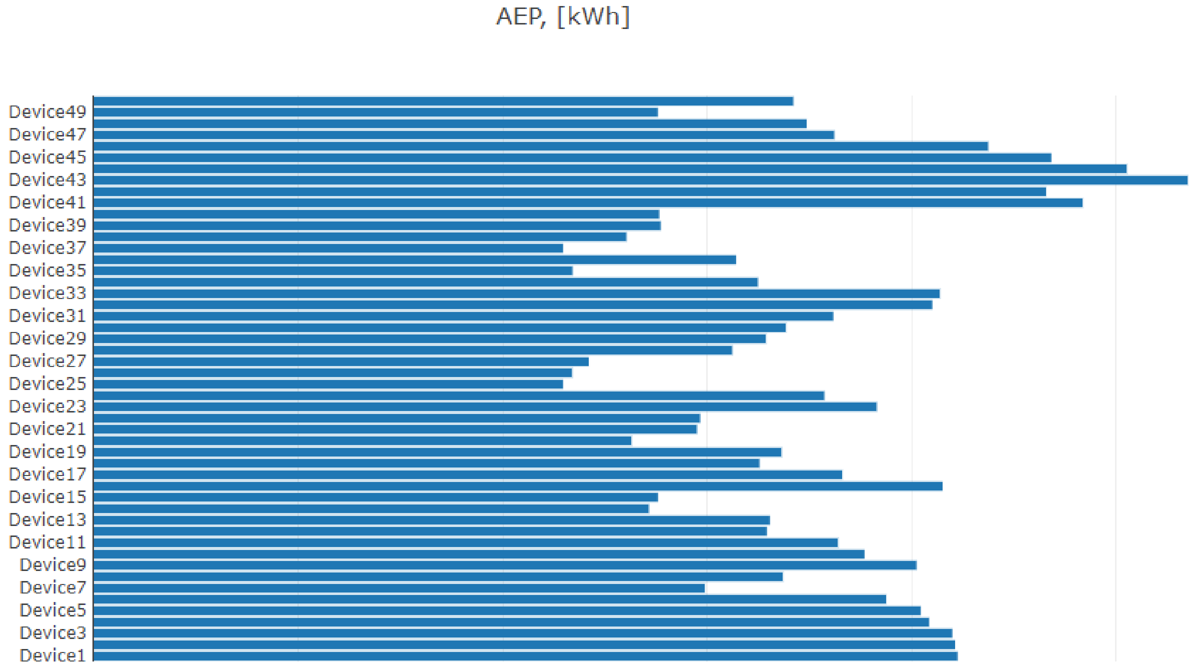


FIGURE 6.22 SABELLA VS6.3 ANNUAL ENERGY PRODUCTION

This has emphasized the need for a powerful optimization tool to maximise energy yield at a particular tidal site for a given number of devices.

For this reason, though it was not the initial objective for VS6.3, SABELLA used the optimization feature in the Energy Capture module. Using both the Monte Carlo and the CMA-ES optimization models, varying the optimization threshold and the "Array Type" parameters, multiple alternative layouts have been generated. Some showed large drops (four times inferior) in energy yields compared to the initial layout when the best layouts were still 30% lower than the layout proposed by SABELLA. Some more help in the GUI on how to adjust parameters to set optimization parameters and achieve the best energy yield properly would be interesting. An interesting feature would be that the proposed optimized layout could be further improved with contribution from the Energy Delivery and Logistics and Maintenance Operations modules to search for a techno-economic optimum.

The user should be able to check that the data processing has been done so far to calculate the energy yield that matches their expectations. He should be allowed to check the information and statistics relative to velocity for all the devices. Thus, he ensures that what was specified in the Site Characterization module is correctly defined.

6.3.5.6 ENERGY TRANSFORMATION

SABELLA was able to run the Energy Transformation module at complexity 3. Except for the definition of the control strategy of the turbine, which has been extensively discussed with the module developers and for which propositions were made in the Validation Task Evaluation Form, SABELLA was able to properly model the technology.

In Table 6.5, a comparison between the reference case study established by SABELLA and results obtained with the Energy Transformation module is provided:

TABLE 6.5 EVALUATION OF RESULTS FROM ENERGY TRANSFORMATION IN VS6.3

Output category		Relative difference (%)	Comments
Design - Weight of the components		-72	
Design - Bill of Materials	Grid conditioning cost	-91	Costs underestimated by the Energy Transformation module by a factor of 11
	Drivetrain cost	-	No model for direct-drive transmission; thus, the cost for the drivetrain was null.
	Generator cost	0	Values for the PMSG were entered via the catalogue, thus matching the real cost
Assessment - Energy	Captured Energy	-15	
	Mechanical Energy	-16	There should be no difference between captured and mechanical energy, as no loss due to friction is accounted for
	Electrical Energy	-29	This large difference is partly explained by the poor modelling of the turbine operation by the Energy Transformation module. Suggestions to add a 'velocity vs omega' table to the Cp/Ct definition section in MC would significantly improve control definition in DTOceanPlus. Another explanation is the complexity to represent generator characteristics with the ET module.
	Grid Conditioned Energy	-28	
Additional calculations from SABELLA	Captured Energy to Mechanical Energy efficiency	0.50	
	Mechanical Energy to Electrical Energy efficiency	-16	This difference is partly explained by the poor modelling of the turbine operation by the Energy Transformation module. Suggestions to add a 'velocity vs omega' table to the Cp/Ct definition section in MC would significantly improve control definition in DTOceanPlus. Another explanation is the complexity to represent generator characteristics with the ET module.

Output category		Relative difference (%)	Comments
	Electrical Energy to Grid Conditioned Energy efficiency	0.55	
Assessment - Economics	Cost of the components	-53	Global costs estimate for the components considered is underestimated by a factor 2 by the Energy Transformation module. This is partly explained by the drivetrain cost being null.

The steps to define the technology in the Energy Transformation module were clearly defined. However, figures in the GUI to help the user define a particular technology would be appreciated, describing the scope of the mechanical conversion, electrical conversion and grid conversion. There should be no ambiguity in the characteristics requested by the user.

The major limitation of the D&A modules is the definition of the control strategy. The "Control" panel functionality is far from what tidal turbine developers would expect. It is not clear what is done via these parameters, even in the documentation. What could be done for turbine control would be defining operational parameters such as rotational speed against flow speed in MC and removing the "Control" panel from ET.

6.3.5.7 ENERGY DELIVERY

The Energy Delivery module has run at complexity 3. The main issue faced by SABELLA was that the user could not model his own Bill Of Plant, set the number and locations of collection points, as only an optimization mode is implemented. The Bill Of Plant designed by the Energy Delivery module is presented in Figure 6.23.

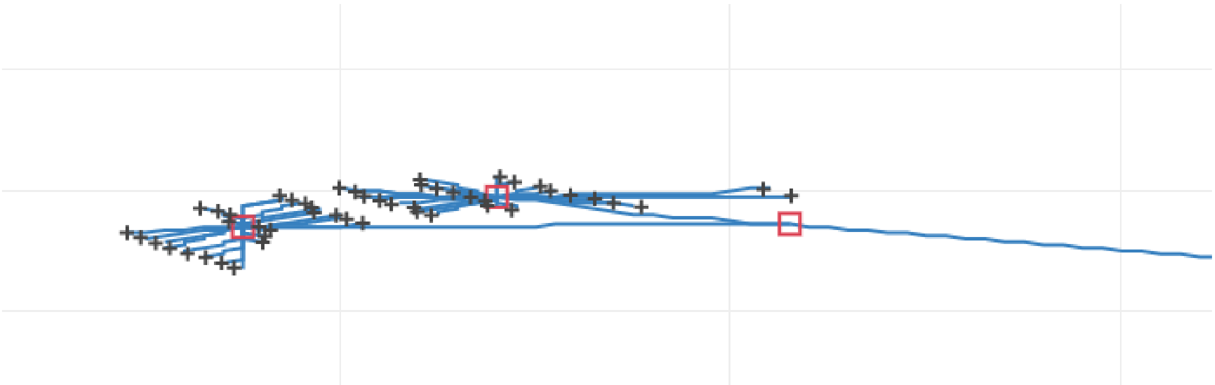


FIGURE 6.23 OUTPUT OF ENERGY DELIVERY FOR ARRAY IN VS6.3

In Table 6.6, a comparison between the reference case study established by SABELLA and results obtained with the Energy Delivery module is provided.

TABLE 6.6 EVALUATION OF RESULTS FROM ENERGY DELIVERY IN VS6.3

Output category		Relative difference (%)	Comments
Annual energy yield		-32	This large difference results from calculations led in the Energy Capture and Energy Transformation modules
Annual losses		316	The energy yield is larger in the real case study than calculated by DTOceanPlus. Because the Energy Delivery module calculates a lower efficiency, losses are more than four times higher in the Energy Delivery module than in the reference case study
Annual efficiency		-4.9	
Transmission network design	Total length of export cable	14	
BOM Summary	Array network costs	-3.5	Models are giving close estimates of costs related to array cables
	Collection point costs	146	In the reference case study, five collection points were used, which did not include the substation and the export cable from the substation to the shore. Thus, comparisons are not relevant
Static cables	Installation cost (proxy)	121	The cost proxy is twice the value estimated by SABELLA

The lease area and the corridor area cannot accommodate complex geometries, and the lease and corridor are modified by the Energy Delivery module. Because of this, in VS6.3, the cable route goes through locations that are out of the area SABELLA is allowed to use.

6.3.5.8 STATION KEEPING

The order of magnitude for both loads and stability-related results seems correct.

6.3.5.9 LOGISTICS AND MARINE OPERATIONS

Due to technical issues which made it impossible to run the Logistics and Maintenance Operations at medium or full complexities, SABELLA had to use the LMO module at the lowest complexity level.

In Table 6.7, a comparison between the real case study established by SABELLA and results obtained with the Logistics and Maintenance Operations module is provided:

TABLE 6.7 EVALUATION OF RESULTS FROM LOGISTICS AND MAINTENANCE OPERATIONS IN VS 6.3

Output category		Relative difference (%)	Comments
Installation solution	Foundation - Total duration	64	Duration of the installation for foundations is 1.6 times higher than planned by SABELLA.
	Foundation - Total costs	176	Costs are 3 times higher than estimated by SABELLA
	Collection point - Total duration	91	Duration of the installation for collection points is 2 times higher than planned by SABELLA. A comparison to SABELLA case study is complicated because there are three additional collection points, but no substation (out of scope) in the reference case study
	Collection point - Total costs	-13	Total costs are inferior to costs calculated by the LMO module
	Cable - Total duration	-82	Duration of the installation for cables is 5.5 times less than planned by SABELLA.
	Cable - Total costs	-89	Duration of the installation for cables is 9.2 times less than planned by SABELLA.
	Device - Total duration	-39	Duration is 65% less than estimated by SABELLA
	Device - Total costs	-74	Costs are 3.8 less high than estimated by SABELLA
Additional SABELLA calculations related to Installation	Total duration	-20	There is only a 25% higher duration for the whole installation, though operations taken separately can differ significantly between results from LMO and the reference case study
	Total costs	-20	As the scopes are different for the two case studies, this metric seems useful, as it may explain differences in CAPEX from the SLC module. Costs are higher in the reference case study from SABELLA
Maintenance solution	Inspection total costs	-84	Costs for Maintenance are underestimated by a factor of 6 in the LMO module. This is partly due to the absence of corrective maintenance and the absence of spare parts replacement costs. On the other side, the preventive maintenance operations as considered by SABELLA did not include as many cable inspection operations
	Inspection total duration	1386	There are 40 times less preventive maintenance operations in the reference case study. This is due to the default preventive maintenance operation in LMO occurring on a yearly basis, which is not an option considered by SABELLA
	Number of operations	3759	

For the Decommissioning phase, the scopes between the results from the LMO module and the reference case study were too different to allow for a straightforward comparison.

We think it is important to have more flexibility in the definition of operations. For example, it would be interesting that the user could set the terminal, the vessel and the sequence of operations in needed. In the preventive maintenance plan developed by SABELLA, turbines are removed from site to be inspected at the maintenance site (in Brest) in a maintenance cycle. In a maintenance cycle, as defined by SABELLA, turbines that have been maintained are reinstalled in the same operation (the vessel stays on the site); the following turbines to maintain are removed to lower marine operations costs. This would be interesting to be able to implement this in DTOceanPlus. An independent tool could be created to define specific operations, under the form of a questionnaire such as "should the nacelle only, or the nacelle and support structure be removed ?" or "will the operation be led offshore or onshore ?", from which a new operation would be created in the catalogue.

For this SABELLA project in the Fromveur straight, the cable cannot be left on site after the end of the project. For this reason, it would be interesting to have a decommissioning operation for the cables added in future releases.

In addition, we found that the results section lacks details. It would be beneficial for the user to be able to delve into the details if needed, as it is hard to understand what is included in the Total duration and costs, and what is displayed in the GANTT chart, without exploring the results json file.

We did not try to use the catalogues (maybe a warning in the LMO GUI that every operation can be adapted to user needs via catalogues would be useful). Documentation to use the catalogues from LMO should be made as user-friendly (parameters names, GUI in the catalogue, references to a section of the documentation to help the user…) as possible.

SABELLA did not have enough time to explore all the possibilities provided by the definition of operations in the Catalogue within the project timeline. However, we found the LMO module really attractive, so we plan to further use its capabilities, spending more resources on the definition of operations closer to our needs, thanks to the Catalogue.

6.3.5.10 SYSTEM PERFORMANCE AND ENERGY YIELD (SPEY)

The System Lifetime Costs module was run, and a comparison between the reference case study and results from SLC was made for some key metrics (see Table 6.8). Calculations related to ACE have not been done, as this metric is not used in the tidal industry.

TABLE 6.8 EVALUATION OF RESULTS FROM SPEY IN VS6.3

Output category		Relative difference (%)	Comments
Efficiency	Relative Array Transformed Efficiency	66	
	Relative Array Delivered Efficiency	-4.8	
Energy Production	Array Lifetime Gross Energy	-35	This large difference is partly explained by the poor modelling of the turbine operation by the Energy Transformation module. Suggestions to add a 'velocity vs omega' table to the Cp/Ct definition section in MC would significantly improve control definition in DTOceanPlus. Another explanation is the complexity to represent generator characteristics with the ET module.
	Array Lifetime Lost Energy	-94	If this corresponds to the loss of energy due to downtime, LMO underestimates this value by a factor of 17 when compared to the reference case study. This is explained by preventive or corrective maintenance operations as modelled by LMO not involving turbines removal from the site for maintenance.
	Array Lifetime Net Energy	-30	

6.3.5.11 SYSTEM LIFETIME COSTS (SLC)

The System Lifetime Costs module was run, and a comparison between the reference case study and results from SLC was made for some key metrics (see Table 6.9). Calculations related to ACE have not been done, as this metric is not used in the tidal industry.

TABLE 6.9 EVALUATION OF RESULTS FROM SLC IN VS6.3

Output category		Relative difference (%)	Comments
Economic Metrics	LCOE	14	
	CAPEX	-12	The user provides the cost of the devices
	Cost equipment	-11	The user provides the cost of the devices
	Cost installation	-30	Total OPEX costs are underestimated by 43% by LMO
	Total OPEX	-84	Total OPEX costs are underestimated by a factor of 6 by LMO
Financial Metrics	Payback period	-24	Financial metrics are significantly worst than estimated by SABELLA due to the 54% difference in energy production
	Internal Rate of Return	63	
	NPV	-1739	

A more detailed breakdown would be appreciated to display economic and financial assessment results (e.g. a year per year cashflow diagram). We noticed that costs related to the decommissioning phase do not appear in the bill of materials.

6.3.5.12 SYSTEM RELIABILITY, AVAILABILITY, MAINTAINABILITY, SURVIVABILITY (RAMS)

Due to issues we encountered in each RAMS module and lack of time to solve these issues, it has not been possible to use the RAMS Assessment Tool within the project timeline.

6.3.5.13 ENVIRONMENTAL AND SOCIAL ACCEPTANCE (ESA)

Due to issues with the ESA modules (Device Info and Electrical Info GUI empty), and lack of time to solve these issues, it has not been possible to use the ESA Assessment Tool within the project timeline.

7. SUMMARY OF DEMONSTRATION ACTIVITY OUTCOMES

This chapter summarises the results of the demonstration activities, firstly with a quantitative assessment of the overall suite of tools, then collated feedback on the Structured Innovation, Stage Gate, and Deployment Design tools in the following sections.

7.1 QUANTITATIVE ASSESSMENT OF THE DTOCEANPLUS SUITE OF TOOLS

Quantitative results for the overall suite of tools from the software evaluation completed by the three tidal developers are collated in this section. The breakdown of cumulative scores for the areas of integration, operation, and installation is shown in Figure 7.1. This is then further broken down, with results from the questions on installation (Table 7.1) shown in Figure 7.2. Results from the questions operation (Table 7.2) are shown in Figure 7.3, and results from the questions in integration (Table 7.3) are shown in Figure 7.4.

Overall, the results are largely positive, with the exception of installation.

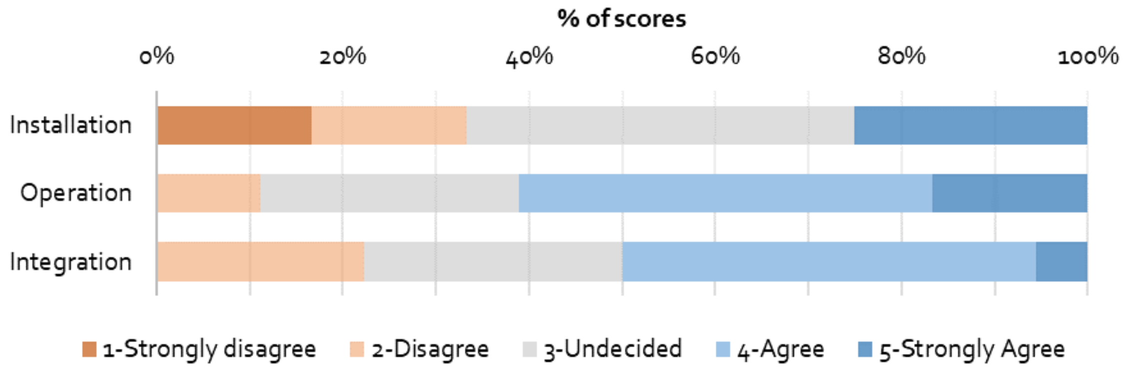


FIGURE 7.1 CUMULATIVE RESULTS OF SOFTWARE EVALUATION FORMS ON INSTALLATION, OPERATION, AND INTEGRATION OF THE WHOLE SUITE OF TOOLS

As shown in Figure 7.2, the documentation of the installation process and prerequisite specifications were found to be clear; however, the process was not so successful. All partners had issues with the installation and running the development version of the tools on their computers.

TABLE 7.1 SOFTWARE EVALUATION QUESTIONS ON INSTALLATION OF GLOBAL SUITE OF TOOLS

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…)

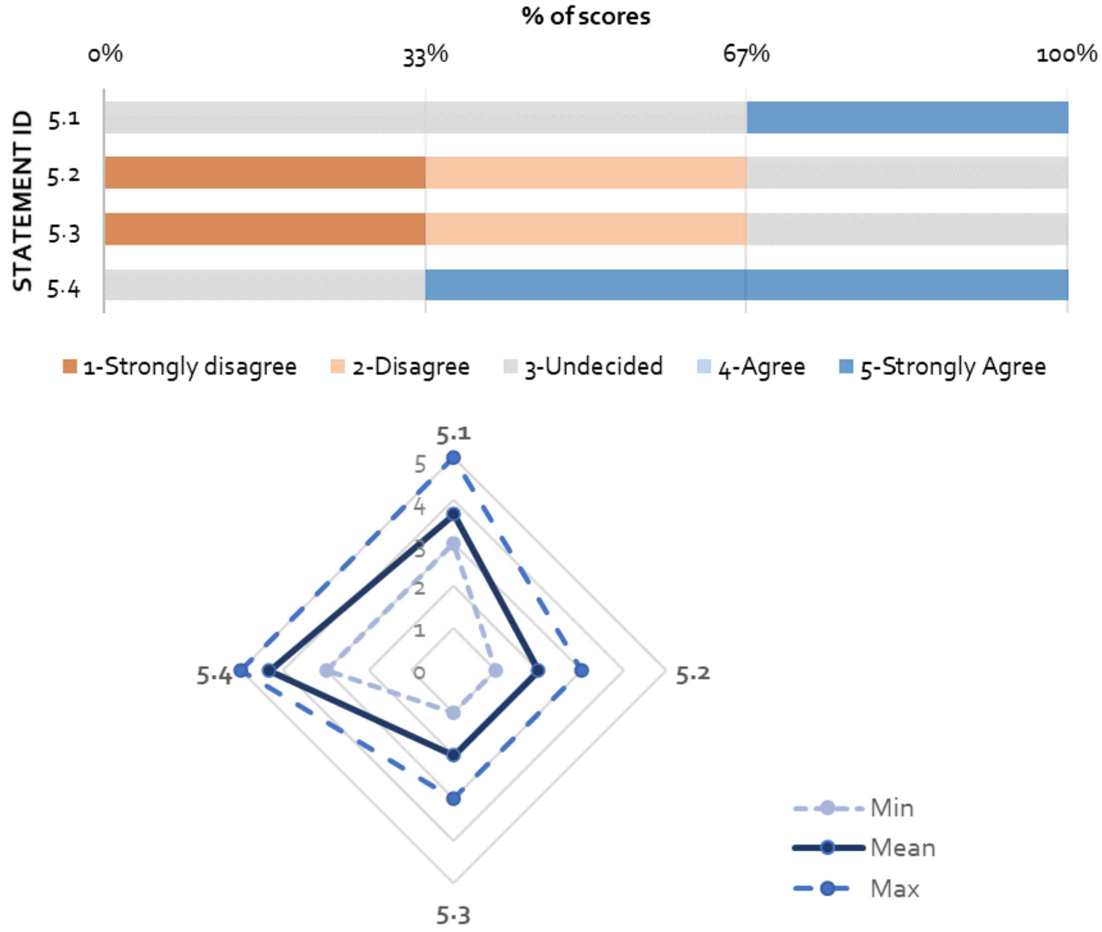


FIGURE 7.2 RESULTS OF SOFTWARE EVALUATION ON INSTALLATION OF GLOBAL SUITE OF TOOLS

The operation of the global suite of tools was largely positive, as shown in Figure 7.3. The level of detail and process of inputting and formatting the data met expectations, as did the guidance on using the tools. Opinions were split on whether the modular architecture added significant value. Handling the complex data flow is possibly another area requiring future improvement.

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

Statement
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

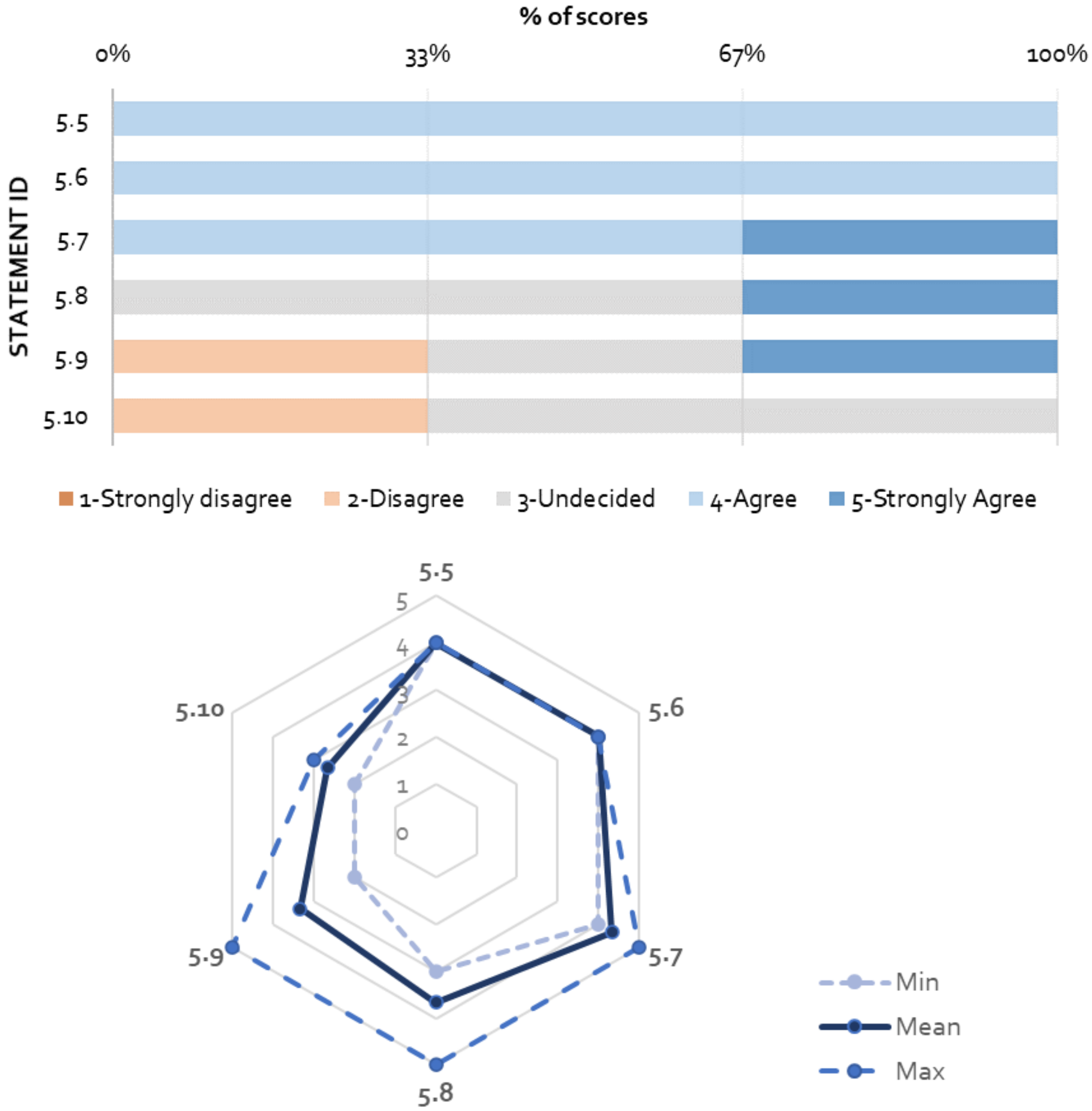
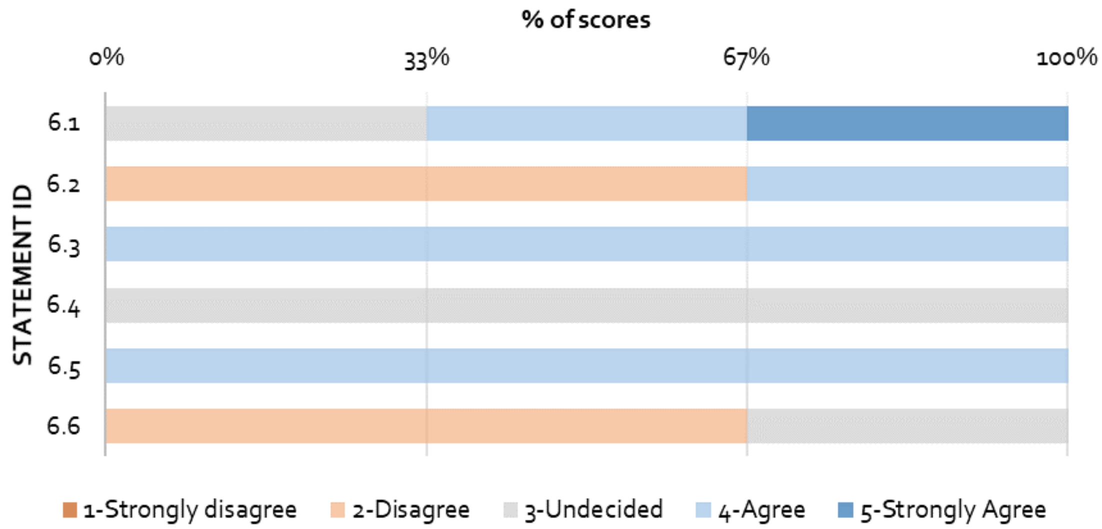


FIGURE 7.3 RESULTS OF SOFTWARE EVALUATION ON OPERATION OF GLOBAL SUITE OF TOOLS

While all tidal developers were able to use the tools in standalone mode, they were not all able to use them fully integrated, as shown in Figure 7.4. The tools were considered to be flexible in their use for different design objectives, giving the user control of the design experience. However, the data flow was not considered to be so efficient, particularly for complex data flows.

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

Statement
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



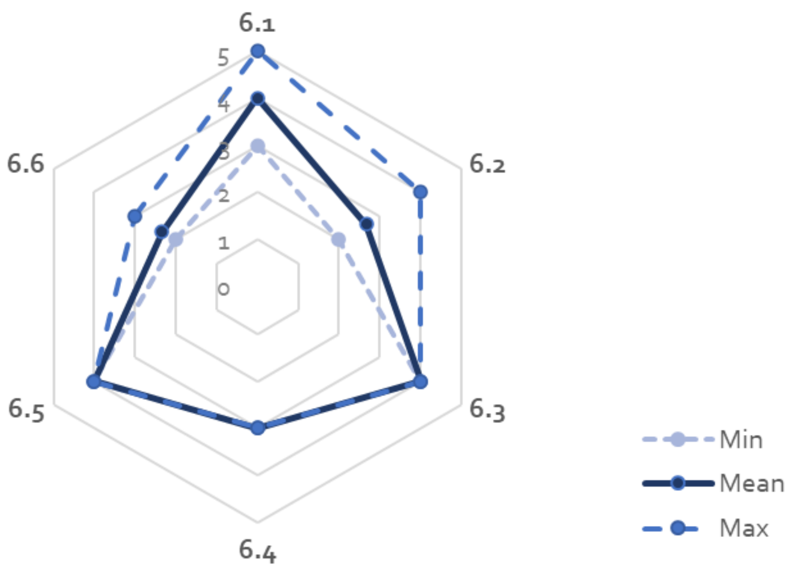


FIGURE 7.4 RESULTS OF SOFTWARE EVALUATION ON INTEGRATION OF GLOBAL SUITE OF TOOLS

7.2 STRUCTURED INNOVATION TOOL VALIDATION STATEMENT

The SI tool has proven to be a powerful and useful option, that could with further development, have the potential to add significant value to marine renewable energy projects. The tool has two very distinct and useful modules. The QFD/TRIZ module does a brilliant job of collating a wide range of data and presenting it in an easy, structured and simple to understand format. The FMEA module brings a fantastic structure and workflow to what can be a tedious and fragmented process.

A major plus for the SI tool is the varying levels of complexity that it can be run at. The input data can be of low resolution enabling the user to quickly process a study; this could be beneficial in the early stages of idea development when trying to quickly disregard ideas that are likely to be advantageous to progress. Then input data can be input at a much higher resolution, then thereafter to carry out a much more detailed assessment whereby the results are more likely to be adopted in design decisions.

As with all software, the ability to export any generated results is useful for further post-processing out with the tool itself. The SI tool can export results from QFD/TRIZ and FMEA in an Excel format, which is a real positive for any users wanting to further examine the outputs to ensure those correct decisions are made.

Despite the fact that the overall experience of the tool was overwhelmingly favourable, there were a couple of points that could be improved and further developed. There is no clear guidance on the number of customer and functional requirements typically required for analysis, leading to long and confusing matrices defining the impacts and correlations between the requirements. Slightly more descriptive tabs would be a benefit for inputs. Although the majority of the tabs are clear, there are a few that it is a little ambiguous. The GUI, although clear and easy to follow and work through, could still do with some work, mainly with the presentation of inputs and ensuring that there is not too much information on the screen, particularly when putting very detailed data.

TRIZ, although obviously, a very powerful tool, is not something that seemingly can be picked up easily. There seems to be a lot of background knowledge and information that is required to get the most out of the tool. A complete worked example in the documentation could be beneficial for early users of the tool, particularly for the TRIZ section. The documentation should also provide an indication of a typical number of requirements defined in a study.

7.3 STAGE GATE TOOL VALIDATION STATEMENT

The Stage tool helps create a clear, consistent assessment between different stakeholders of what is expected at each stage of technology development. The stage gate framework enables developers to assess and demonstrate their progress to assessors (including investors), enabling a key marker indicating how far a company is in its development. A real area of strength within the tool is the improvement areas feature. It is extremely helpful for early-stage technologies in particular as it helps guide the user in the areas it is more important to focus their R&D effort on. The ability to run the tool in integrated mode enables the users to create or select innovative concepts based on these improvement areas for the design.

One area of weakness within the current tool is that the user must define the threshold metrics for themselves. This means that there is no bar set for performance in each area of the evaluation. Ideally, there should be a threshold for each stage gate to create a more standardised and consistent assessment. Unfortunately, this information does not as yet exist within the ocean energy sector.

7.4 DEPLOYMENT DESIGN TOOLS VALIDATION STATEMENT

Overall, the tools show promise if further development and testing of the integrated operation can be performed. Small amounts of additional functionality, for example, setting specific parameters to the assumptions made by a developer, or adding iterative design loops including between modules, could significantly improve the value of the tools.

Results from most modules look reasonable, although some discrepancies were noted. While it was not possible to fully validate these with the industrial partners' real projects, the tools generally matched their expectations and engineering judgement. Further use and validation of the tools by all the tidal developers are expected to continue beyond the DTOceanPlus project.

The Logistic and Marine Operations module, in particular, appears to be a very useful tool. Although some vessels/operations are based on more expensive offshore wind practices, these can be edited within the tool catalogues to better reflect low-cost operations used by the tidal developers in their projects.

However, some of the modules were quite complicated. None of the industrial partners could fully use their own site data within the scope of the demonstration scenarios and had to resort to testing with one of the included sites. The Energy Transformation module was somewhat opaque in how the results were obtained, and these did not match the experience of the tidal developers. This also applies to the associated catalogues of energy transformation equipment. A more standard load-efficiency curve might better represent the generator, reducing the complexity of inputs required.

There are also a number of points to be improved, principally GUI refinements in various parts of the software. For example:

- Providing a consistent workflow between tools.
- Showing layers of site information (bathymetry, tidal resource, device positions, etc.) on one plot.
- Adding additional contextual help to clarify the specific meaning of parameters, etc. Particularly for Machine Characterisation, explaining how and where these will be used in the other modules. Consider diagrammatic representation parameters
- Being clearer about the progress of calculations.
- Being clearer about coordinate systems used (as some modules use WGS84 and other UTM).

Additionally, it would be useful to add more flexibility in the design assumptions used, for example:

- Being able to specify current and wave resources separately in Site Characterisation and have the option to use default values for only waves.

- Inputting user-defined locations of collection points in Energy Delivery, rather than just optimisation.
- Selecting the vessels/port terminals used, or defining custom operations, in the LMO module.

The ability to export results in other tools, e.g. site maps as DWG/DXF files in UTM coordinates, would be useful for some users.

It was also noticed that some of the cost values suggested by default do not match the expectations of the industrial partners, although many of these can be adjusted in the catalogues.

8. CONCLUSIONS

Overall, the tools show promise if further development and testing of the integrated operation can be performed, taking them beyond the TRL6 achieved in the DTOceanPlus project.

The three industrial partners have been impressed with the initial development of the tools; there is an incredible scope and potential for further development into a tool that would benefit the nascent marine renewable energy industry. One of the greatest strengths of the tools is the linked and integrated GUI. It makes the progression and workflow through each tool easy and simple to follow. When operating in integrated mode, the ability of the tools to 'talk' to each other makes sure there is good continuity within the project. As detailed below, Nova are already committed to the EnFAIT project. Orbital and Sabella are also very willing to continue developing and validating the tools should the opportunity arise.

Further demonstration and validation of the deployment tools will be conducted as part of the Enabling Future Arrays in Tidal (EnFAIT) project[2] by The University of Edinburgh and Nova Innovation. The EnFAIT project is based around the world's first in-sea tidal array, which has been in operation since 2016 and is currently being expanded from 4 to 6 turbines. This is effectively an extension of VS6.1. Nova Innovation and The University of Edinburgh previously compared the earlier version DTOcean2 tool outputs with the actual array design choices made. This provided many lessons on the design of a real-world array into the DTOcean Plus project. Further work to improve the validation of the new DTOcean Plus deployment tools could therefore be undertaken in EnFAIT.

[2] Enabling Future Arrays in Tidal, H2020 Grant Agreement № 745862, https://www.enfait.eu/

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