



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

Deliverable D7.6

Final suite of design tools for devices and arrays

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EXECUTIVE SUMMARY

This deliverable presents the main components of the final and most important result of the project, namely the integrated suite of Design Tools for Ocean Energy Systems Innovation, Development and Deployment. The toolset includes:

- Installer.
- Catalogues.
- Online documentation.
- Example test cases.

A public repository has been created to ensure long-term availability and exploitation of the tools developed during the project. This repository is aimed at giving access to the full suite of design tools (and underlying documentation) developed within the project during and beyond the project lifespan. The project repository complies with the open source policy.

The DTOceanPlus suit of tools is released under the GNU Affero General Public License v3. See <https://www.gnu.org/licenses/agpl.html> for more information.

The latest version of the DTOceanPlus tool can be downloaded at:
https://gitlab.com/dtoceanplus/dtop_inst/-/packages



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ABBREVIATIONS AND ACRONYMS

AD	Assessment Design
CM	Catalogues Module
DD	Deployment Design
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
KPI	Key Performance Indicator
LCoE	Levelised Cost of Energy
LMO	Logistics and Marine Operations
MC	Machine Characterisation
MM	Main Module
MRE	Marine Renewable Energy
OE	Ocean Energy
O&M	Operation and Maintenance
PTO	Power Take Off
RAMS	Reliability Availability Maintainability Survivability
RM	Reference Model
SC	Site Characterisation
SG	Stage Gate
SI	Structured Innovation
SK	Station Keeping
SLC	System Lifetime Costs
Tx.x	Task x.x within a work package
WEC	Wave Energy Converter
WP	Work Package



1. INTRODUCTION

1.1 DTOCEANPLUS PROJECT

The DTOceanPlus Project has developed and demonstrated a suite of 2nd generation advanced design tools for the selection, development, and deployment of ocean energy systems. It covers the two most developed sources of ocean energy, namely tidal stream and wave energy. These software tools provide the basis for a single, integrated, open-source solution that will support the entire innovation and development process for ocean energy sub-systems, devices and arrays; aligning innovation and development processes with those used in mature engineering sectors.

The DTOceanPlus project builds on the existing open-source code of DTOcean, adding significant new features and functionality. Development and validation of the code is expected to continue beyond the end of the DTOceanPlus project, both as part of ongoing work by consortium partners, and within the framework of other projects.

The aim of the DTOceanPlus project was to develop and demonstrate the tools to TRL6, i.e. demonstrated in a relevant environment, having previously been validated both in a relevant environment (TRL5) and in a lab environment (TRL4) [1]. Continued future development of the tools can bring them to TRL9, as discussed in the Plan for Exploitation [2].

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

- ▶ **Main Application (MM)**, to manage projects and design workflow.
- ▶ **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 operation plans related to the installation, operation, maintenance, and decommissioning operations.
- ▶ **Assessment Design tools (AD)**, to evaluate projects in terms of key parameters:
 - *System Performance and Energy Yield (SPEY)*: to evaluate projects in terms of energy performance.
 - *System Lifetime Costs (SLC)*: to evaluate projects from the economic perspective.
 - *System Reliability, Availability, Maintainability, Survivability (RAMS)*: to evaluate the reliability aspects of a marine renewable energy project.
 - *Environmental and Social Acceptance (ESA)*: to evaluate the environmental and social impacts of a given wave and tidal energy projects.



These are supported by underlying common digital models, or Digital Representation (DR) ocean energy projects and a global database or catalogue module (CM) containing components and activities. These are shown graphically in Figure 1.1.

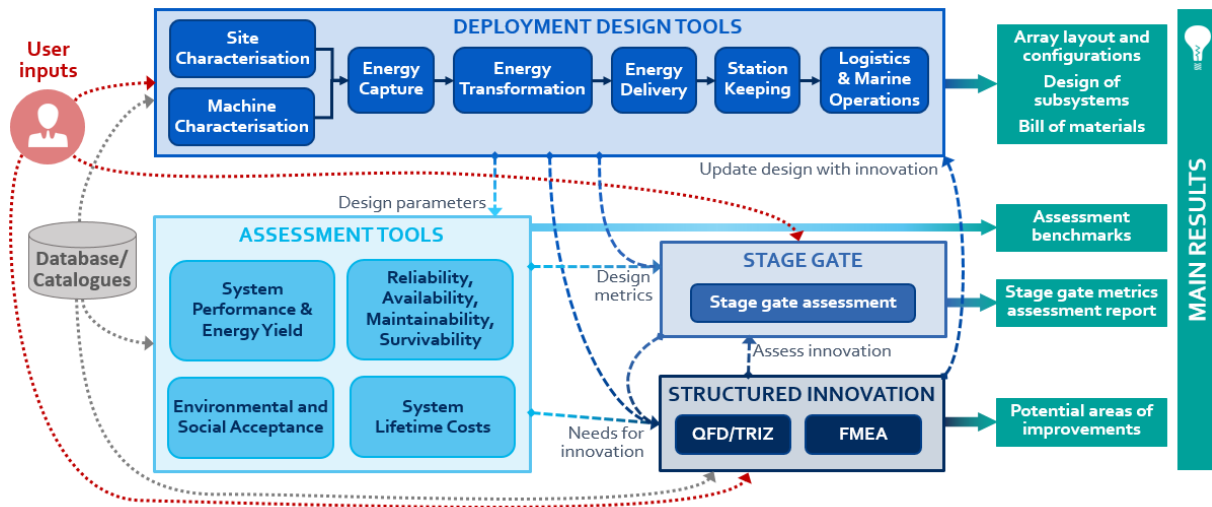


FIGURE 1.1: REPRESENTATION OF THE DTOCEANPLUS MODULES, MAIN LINKAGES, AND OUTPUTS

1.2 SCOPE OF THE REPORT

This report documents the delivery D7.6 “Full suite of design tools for devices and arrays” of the task T7.3 “Design tools integration, deployment and maintenance”. This was led by Open Cascade with the participation of Tecnalia.

This deliverable documents the final version of the DTOceanPlus suite of tools produced within the DTOceanPlus project. It is composed of the software itself, with an installation procedure and supporting documentation (i.e. technical and user manuals, tutorial, example test cases). This deliverable is public.

1.3 OUTLINE OF THE REPORT

This report is structured as follows:

- ▶ **Section 1: Introduction.** Explains the context and the objectives of the DTOceanPlus project and briefly describes the scope of this document.
- ▶ **Section 2: DTOceanPlus Installation.**
- ▶ **Section 3: DTOceanPlus Catalogues.**
- ▶ **Section 4: Online Documentation.**
- ▶ **Section 5: Example Test Cases.**
- ▶ **Annex I: Versions of the modules.** Lists the versions of the modules composing the version 1.0 of the DTOceanPlus suite of tools.

2. DTOCEANPLUS INSTALLATION

2.1 SUMMARY

DTOceanPlus is composed of 15 functional interacting Modules designed and provided by correspondent Proxy, Docker Stacks, Services and production Images.

TABLE 2.1: STRUCTURE OF THE DTOCEANPLUS TOOLS

Category	Module/Tool	Name	Main Developer
Management	MM	Main Module	OCC
Management	CM	Catalogue Module	OCC
Innovation	SI	Structured Innovation	ESC
Development	SG	Stage Gate	WES
Deployment	SC	Site Characterisation	FEM
Deployment	MC	Machine Characterisation	AAU
Deployment	EC	Energy Capture	AAU
Deployment	ET	Energy Transformation	TECNALIA
Deployment	ED	Energy Delivery	UEDIN
Deployment	SK	Station Keeping	FEM
Deployment	LMO	Logistics and Marine Operations	WAVEC
Assessment	SPEY	System Performance and Energy Yield	TECNALIA
Assessment	RAMS	Reliability, Availability, Maintainability, Survivability	AAU
Assessment	SLC	System Lifetime Costs	WAVEC
Assessment	ESA	Environmental and Social Acceptance	FEM

DTOceanPlus uses Docker Engine [<https://www.docker.com/>], an open-source containerization technology for building and containerizing the DTOP modules. Docker production images are available in Container Registry of correspondent public GitLab repositories of DTOceanPlus modules.

For DTOceanPlus Modules Services (microservices) orchestration Docker in SWARM mode is used. Traefik proxy Edge Router interacts with Docker registry/orchestrator API and generates the properly resolved routes to DTOceanPlus Module Services (microservices).

These routes allow access to DTOceanPlus Modules' Frontends and Backends as interacting Web applications for final DTOceanPlus users.

The DTOceanPlus application is available for the following Operating systems:

- ▶ Windows 10 Pro
- ▶ MacOS 11
- ▶ Linux (tested with Debian 10).

Please refer to the installation procedure for the complete prerequisites and system requirements for each operating system.



To provide simple and unified DTOceanPlus Installation on different HWs and Operative Systems, Installation and Re/Un-Installation is implemented basing on Bash scripts with using "whiptail" program for user-friendly UI. A separate Windows installer executable has also been produced to simplify installation on that platform.

2.2 MAIN INSTALLATION STEPS

The installation packages are available at <https://gitlab.com/groups/dtoceanplus/-/packages>.

- ▶ Download and unarchive the DTOceanPlus installation archive suitable for your operating system (Windows, Linux or MacOS) on a local workstation or on a company server.
- ▶ Create the directory for DTOceanPlus installation and extract the content of the archive to this directory.
- ▶ For Windows create the "cygwin" environment by running "cygwin_inst.bat" and open its bash terminal by dtop_inst.bat.
- ▶ Execute the installation script ".dtop_inst.sh" from a bash terminal.
- ▶ When it would be necessary to (re)deploy module(s) execute the script ".dtop_redeploy.sh" from a bash terminal.

Open an installed DTOceanPlus module using URL "<module nickname>.dtop.localhost" in a browser.

To uninstall run the script ".dtop_uninst.sh".

You can find the necessary details and illustrations of these main steps in other documentation files mentioned above.

NB: DTOceanPlus SC module needs and uses the set of own basic data files. These SC data files are provided in the quite large archive. The archive should be downloaded separately from the dedicated repositories (https://gitlab.com/dtoceanplus/dtop_sc_databases) and copied into DTOceanPlus installation directory to be used by the installation procedure.

More info: https://gitlab.com/dtoceanplus/dtop_inst/-/blob/master/INSTALLATION.md



3. DTOCEANPLUS CATALOGUES

The DTOceanPlus suite of tools include catalogues of components and reference data that are introduced on this page. These components are used by the Deployment Design tools in the design process, and by the System Lifetime Costs Assessment tool for benchmarks. Used by the different modules, the catalogues are grouped by themes as follows:

- ▶ **Power Take Off Components** used by Energy Transformation
 - Air turbines
 - Gearboxes
 - Hydraulic transmission systems
 - Generators
 - Power converters
 - Control systems
- ▶ **Electrical Network Equipment** used by Energy Delivery
 - Static cables
 - Dynamic (umbilical) cables
 - Wet-mate connectors
 - Dry-mate connectors
 - Collection Points
 - Transformers
- ▶ **Mooring Line and Anchors** used by Station Keeping
 - Mooring line properties
 - Drag anchor dimensions
- ▶ **Logistical Infrastructure and Equipment** used by Logistics and Marine Operations (LMO)
 - Activities
 - Speeds for different operations
 - Installation operations
 - Maintenance operations
 - Decommissioning operations
 - ROVs
 - Divers
 - Cable burial equipment
 - Cable protection equipment
 - Piling equipment
 - Terminals at ports
 - Vessel operations
 - Vessels
- ▶ **Cost Benchmarks** used by System Lifetime Costs

More info on the catalogues is given in the documentation accessed through GitLab and in the three corresponding datasets published on Zenodo:



- ▶ Electrical components [[DOI:10.5281/zenodo.5215642](https://doi.org/10.5281/zenodo.5215642)],
- ▶ Station Keeping components [[DOI:10.5281/zenodo.5336289](https://doi.org/10.5281/zenodo.5336289)], and
- ▶ Logistical and marine operations [[DOI:10.5281/zenodo.5222431](https://doi.org/10.5281/zenodo.5222431)].



4. ONLINE DOCUMENTATION

As described in D9.9 Knowledge exchange of educational and training material [1], a comprehensive set of online documentation has been developed for the DTOceanPlus tools, covering both the integrated suite and the individual modules. For each, the documentation includes:

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

The online documentation can be accessed at <https://dtoceanplus.gitlab.io/documentation/>. The overall documentation is summarised in the next subsections.

4.1 TUTORIALS

The tutorials are step-by-step instructions on using DTOceanPlus for new users. It is suggested to follow these tutorials in order.

- ▶ Showcasing features of the DTOceanPlus suite of tools
 1. Use the Deployment Design tools to design an optimal array layout
 2. Use the Assessment Design tools to assess device/array metrics
 3. Stage Gate
 4. Structured Innovation
- ▶ Installing and using the DTOceanPlus suite of tools
 1. Installing the DTOceanPlus suite of tools:
 - Installing DTOceanPlus on Windows 10
 - Installing DTOceanPlus on Linux/MacOS

Getting started with DTOceanPlus. Use of each tool is described in the relevant section of the documentation.

4.2 HOW-TO GUIDES

The how-to guides show how to achieve specific outcomes using DTOceanPlus.

- ▶ Understand levels of complexity in DTOceanPlus
- ▶ Understand the modular architecture of the DTOceanPlus tools
- ▶ Use the Main Module
- ▶ Use the Catalogue Module
- ▶ Resolving issues arising in the Deployment Design tools
- ▶ Troubleshooting common issues with DTOceanPlus
- ▶ Using Portainer to monitor/troubleshoot DTOceanPlus



4.3 BACKGROUND ON THE OVERALL SUITE OF TOOLS

- ▶ Detailed use cases for DTOceanPlus
- ▶ Development of the DTOceanPlus suite of tools, summarising the projects and partners involved in the development.
- ▶ Ocean Energy Technologies considered
- ▶ Market Analysis reports

4.4 API REFERENCE

The API reference section documents the code of the classes, API, and GUI for software development of the Main Module, Catalogues, and Digital Representation.



5. EXAMPLE TEST CASES

Example Test Cases have been adapted in accordance with available data produced by the Reference Model Project (RMP) sponsored by the US Department of Energy (DoE) Wind and Water Power Technologies Program. This project aims to produce on-propietary Reference Models (RM) of technology designs as study objects for open-source research and development programs [1].

The RMs used are RM₁ and RM₃; both power performance and velocity measurements were collected to assess their interaction with the surrounding environment. The outputs of the tests have been used as inputs for the modules developed under DTOceanPlus, as showed in Figure 5.1.

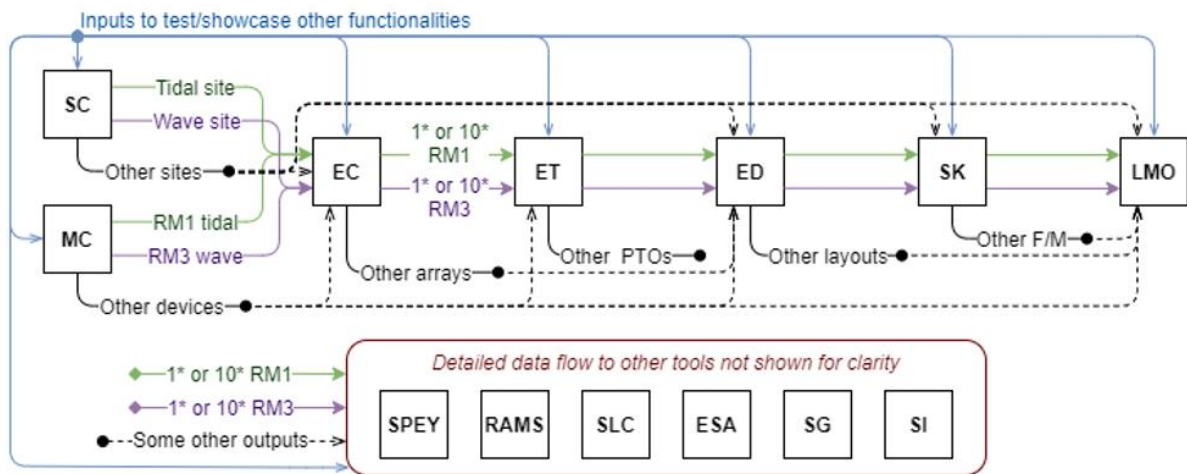


FIGURE 5.1: FLOW OF REFERENCE CASES/DATA BETWEEN THE TOOLS

5.1 RM1 TIDAL TURBINE

The RM1 device is a dual variable-speed variable-pitch axial-flow tidal turbine device. The rated power for the dual rotor unit is 1.1 MW. The main dimensions of the RM1 device are illustrated in Figure 5.2.

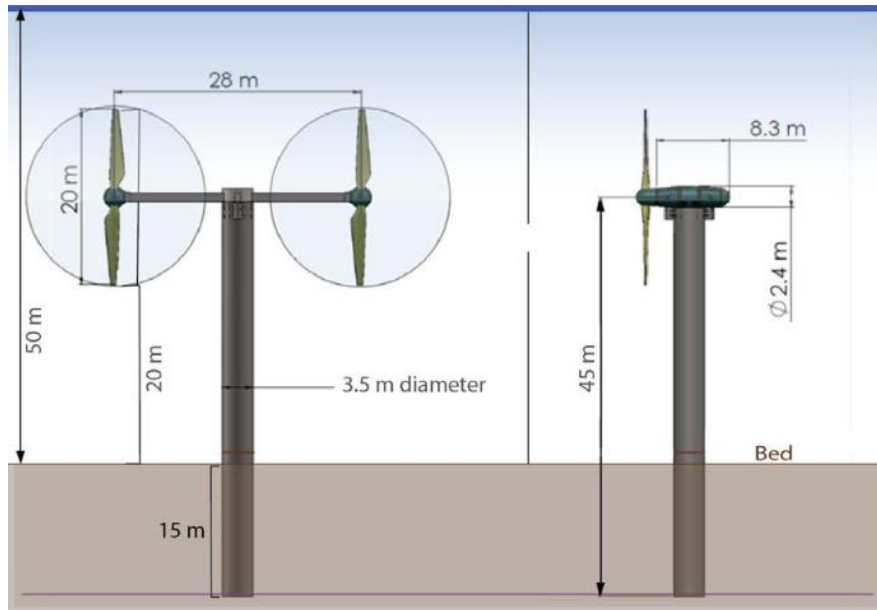


FIGURE 5.2: RM1 DEVICE PROFILE AND PLAN VIEWS DIMENSIONS

The main source of data for this validation scenario is the publication [2]. The study case in the paper has been conducted with the aid of the DTOcean software, v2.0¹. The resulting cable and turbine layout are represented in Figure 5.3.

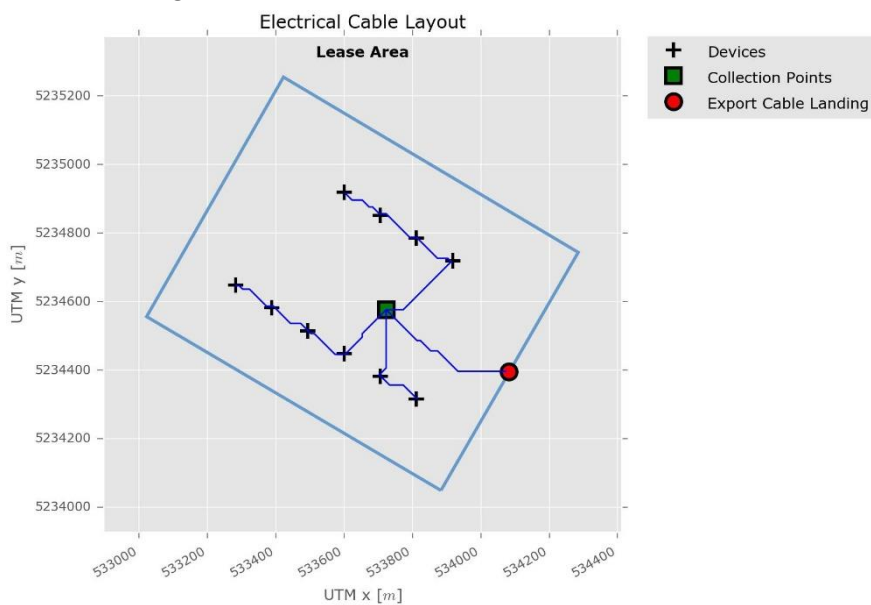


FIGURE 5.3: CABLE AND TURBINE LAYOUT FOR THE VALIDATION SCENARIO 1

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

The tidal energy resource for RM1 was developed from site information on the Tacoma Narrows tidal site in Puget Sound. For this study, a tidal location in Europe with similar site characteristics was considered. The black line in Figure 5.4 denotes the reference current speed frequency histogram selected for the reference model (mean of all sites), with $U_{\max}=3$ m/s.

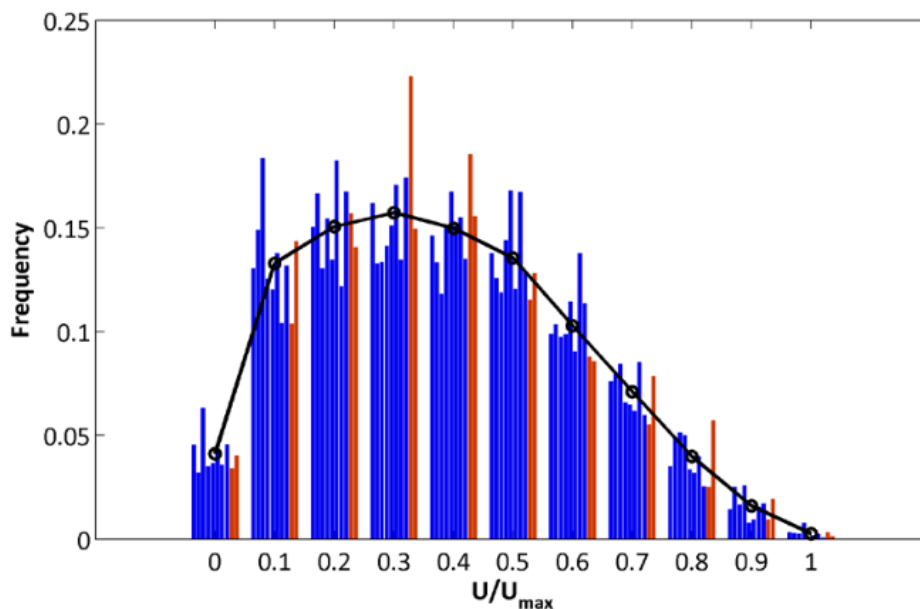


FIGURE 5.4: NON-DIMENSIONAL MID-DEPTH CURRENT SPEED FREQUENCY HISTOGRAMS FOR PUGET SOUND [3]

5.2 RM₃ WAVE ENERGY CONVERTER

Wave Energy Converters (WECs) are based on Sandia’s Reference Model 3 (RM₃). The RM₃ device is a heaving point absorber, also referred to as a wave power buoy. RM₃ uses a Hydraulic PTO whose components are located inside the vertical column. The rated capacity of this unit is 260 kW, with a conversion efficiency of 80% from mechanical to electrical energy. The overall design and dimensions of the RM₃ device are illustrated in Figure 5.5 [3].

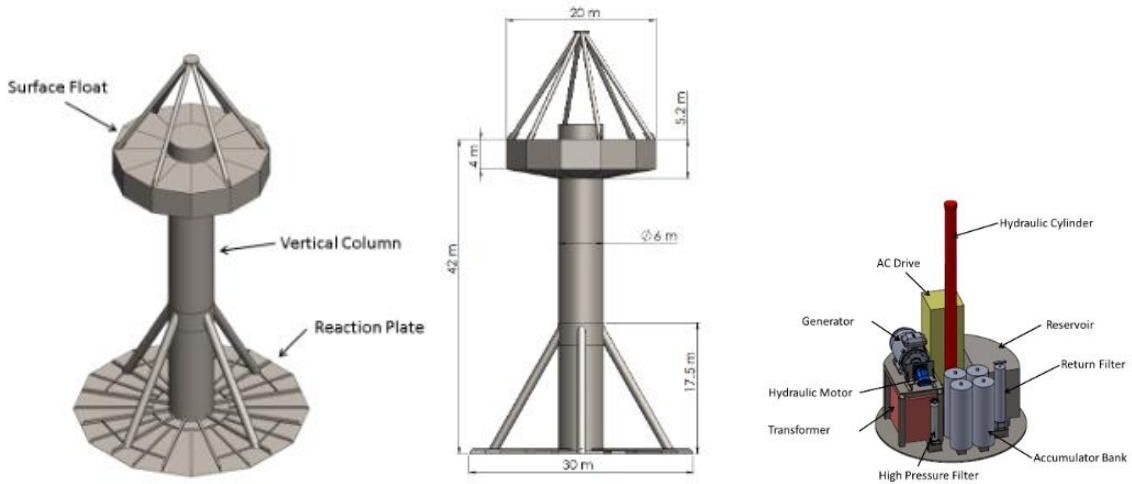


FIGURE 5.5: RM₃ DEVICE DESIGN AND DIMENSIONS

The main source of data for this validation scenario is based on the example that can be downloaded from DTOcean software, v2.0². The resulting cable and turbine layout are represented in Figure 5.6.

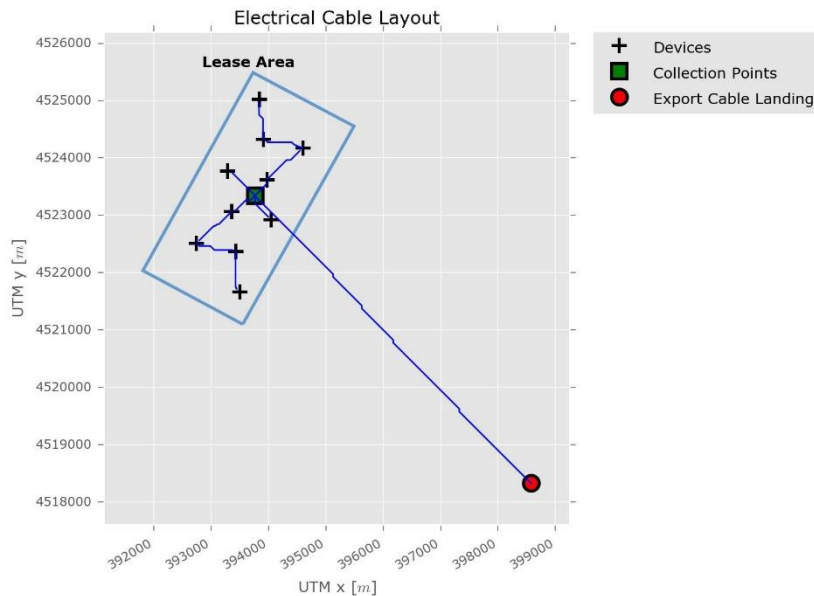


FIGURE 5.6: CABLE AND TURBINES LAYOUT FOR THE VALIDATION SCENARIO 2

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

The reference wave energy resource for RM₃ was developed from site information collected near Eureka in Humboldt County, California [3]. Again, for convenience and this study's purposes, a wave location in Europe with similar site characteristics is considered. The mean reference site wave energy density is 33.5 kW/m.

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

FIGURE 5.7: WAVE SCATTER DIAGRAM FOR EUREKA, HUMBOLDT COUNTY, CALIFORNIA



6. REFERENCES

- [1] Hill, C., S. Neary, V., Gunawan, B., Guala, M., Sotiropoulos, F., "U.S. Department of Energy Reference Model Program RM1: Experimental Results," 2014.
- [2] M. Topper, S. Olson and J. Roberts, "Techno-Economic Modelling of Tidal Energy Converter Arrays in the Tacoma Narrows," *Journal of Marine Science and Engineering* , vol. 8, no. 9, 2020.
- [3] V. S. Neary, M. Lawson, M. Previsic, A. Copping, K. C. Hallett, A. LaBonte and D. Murray, "Methodology for design and economic analysis of marine energy conversion (MEC) technologies. SANDIA Rerport SAND2014-9040," SANDIA, 2014.



ANNEX I: VERSIONS OF THE MODULES

The versions of the modules included in the version 1.0 of the DTOceanPlus suite of tools are the following:

TABLE I.1: VERSIONS OF THE MODULES

Module/Tool	Name	Version
MM	Main Module https://gitlab.com/dtoceanplus/dtop_mm	1.0.0
CM	Catalogue Module https://gitlab.com/dtoceanplus/dtop_catalogs	1.0.0
SI	Structured Innovation https://gitlab.com/dtoceanplus/dtop_si	v1.1.1
SG	Stage Gate https://gitlab.com/dtoceanplus/dtop_sg	1.0.0
SC	Site Characterisation https://gitlab.com/dtoceanplus/dtop_sc	V1.5.2
MC	Machine Characterisation https://gitlab.com/dtoceanplus/dtop_mc	v1.0.5
EC	Energy Capture https://gitlab.com/dtoceanplus/dtop_ec	v1.1.6
ET	Energy Transformation https://gitlab.com/dtoceanplus/dtop_et	v1.15.5
ED	Energy Delivery https://gitlab.com/dtoceanplus/dtop_ed	0.1.2
SK	Station Keeping https://gitlab.com/dtoceanplus/dtop_sk	V1.5.5
LMO	Logistics and Marine Operations https://gitlab.com/dtoceanplus/dtop_lmo	v1.3.11
SPEY	System Performance and Energy Yield https://gitlab.com/dtoceanplus/dtop_spey	v1.7
RAMS	Reliability, Availability, Maintainability, Survivability https://gitlab.com/dtoceanplus/dtop_rams	v1.0.2
SLC	System Lifetime Costs https://gitlab.com/dtoceanplus/dtop_slc	0.0.5
ESA	Environmental and Social Acceptance https://gitlab.com/dtoceanplus/dtop_es	V1.2.1





CONTACT DETAILS

Mr. Pablo Ruiz-Minguela
Project Coordinator, TECNALIA
www.dtoceanplus.eu



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