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

Deliverable D2.2

Functional requirements and metrics of 2nd generation design tools

Lead Beneficiary	University of Edinburgh
Delivery Date	30/10/2018
Dissemination Level	Public
Status	Released
Version	1.0
Keywords	Operational requirements; Functional requirements; Metrics; User consultation; State-of-the-art

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

Disclaimer

Document Information

Grant Agreement Number	785921
Project Acronym	DTOceanPlus
Work Package	WP 2
Related Task(s)	T2.2
Deliverable	D2.2
Title	Functional requirements and metrics of 2nd generation design tools
Author(s)	Donald R Noble, Anup Nambiar, Tianna Bloise-Thomaz, Henry Heffrey (The University of Edinburgh); Vincenzo Nava, François-Xavier Faÿ, Pablo Ruiz-Minguela, Imanol Touzon, Joseba Lopez Mendia (Tecnalia); Stuart Bradley, Nick Eraut, Inès Tunga (Energy Systems Catapult); Jillian Henderson, Jonathan Hodges (Wave Energy Scotland); Nicolas Germain, Charles Spraul, Georges Safi (France Energies Marines); Francisco Fonseca, Marta Silva (WavEC); Francesco Ferri (Aalborg University); Nicolas Relun (EDF); Frédéric Pons (Open Cascade)
File Name	DTOCeanPlus D2.2 Functional requirements UEDIN 2018-10-30_v1.0.docx

Revision History

Revision	Date	Description	Reviewer
0.1	29/08/2018	Draft structure of functional requirements	TLs
0.2	14/09/2018	Working draft with first sections	TLs
0.5	14/10/2018	Working draft incorporating all draft sections from TLs	TLs
0.8	26/10/2018	Full Draft for QA review	WES, Coordinator
1.0	30/10/2018	Released version for the EC	EC

EXECUTIVE SUMMARY

This document, D2.2 Functional requirements and metrics of 2nd generation design tools, is a deliverable of the DTOceanPlus project, which is funded by the European Union's H2020 Programme under Grant Agreement №785921.

The overarching objective of the DTOceanPlus project is to develop and demonstrate an open source, integrated suite of 2nd generation design tools for ocean energy technologies that support the entire technology innovation process. The suite of design tools will be applicable to different levels of technology (from sub-systems, to devices and arrays) and across all stages (from concept, to development and deployment). DTOceanPlus will assist users in working towards an optimal solution based on information available at a particular stage. The DTOceanPlus suite of design tools can help accelerate the development of the Ocean Energy sector and reduce the technical and financial risks of devices and arrays to achieve the deployment of cost-competitive wave and tidal arrays.

A coherent set of requirements have been developed for the DTOceanPlus suite of design tools based on analysis of gaps between the current state-of-the-art tools, learning from the DTOcean project, and the stakeholder expectations identified in the user consultation exercise. The requirements in this document are split into general requirements for the overall suite of tools, and specific requirements (functional, operational, user, interfacing, and data) for each of the design tools that will be developed as part of this, which are split by work package and task. They will act as user specifications for the tool development work packages, and will focus the development effort to best meet the needs of the ocean energy industry. Subsequent tasks of the DTOceanPlus project will develop these requirements into more detailed technical requirements and software specifications, prior to software coding and integration, then testing and validation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

AEP	Annual Energy Production
API	Application Programming Interface
BIM	Building Information Modelling
BV	Bureau Veritas
CAD	Computer Aided Drawing/Design software
CAPEX	Capital Expenditure
CFD	Computational Fluid Dynamics software
cFMEA	Concept-design Failure Modes and Effects Analysis
CSV	Comma Separated Variables
dFMEA	Design Failure Modes and Effects Analysis
Dx.x	Deliverable x.x from a task or work package
EnFAIT	Enabling Future Arrays in Tidal
ESC	Energy Systems Catapult
FMEA	Failure Modes and Effects Analysis
GIS	Geographical Information Systems
GUI	Graphical User Interface
HoQ	House of Quality Matrix
IP	Intellectual Property
IRR	Internal Rate of Return
LCOE	Levelised Cost of Energy
NPV	Net Present Value
O&M	Operations and Maintenance
OEC	Offshore Energy Converter (aggregate term for WEC & TEC)
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
PTO	Power Take-Off
QFD	Quality Function Deployment
R&D	Research and development
RAMS	Reliability, Availability, Maintainability, Survivability
Tx.x	Task x.x within a work package
TEC	Tidal Energy Converter
TRIZ	*Teoriya Resheniya Izobretatelskikh Zadatch*, (theory of inventive problem solving)
TRL	Technology Readiness Level
UEDIN	University of Edinburgh
WEC	Wave Energy Converter
WES	Wave Energy Scotland
WP	Work Package

DTOCEANPLUS TERMINOLOGY

The following hierarchy is used to describe DTOceanPlus, illustrated in Figure 0.1:

Suite of Tools Over-arching term for all the tools in DTOceanPlus (shown as a dark blue dashed line in Figure 0.1).

Design Tools The DTOceanPlus suite comprises four design tools (shown in blue): 'Structured Innovation', 'Stage Gate', 'Deployment', and 'Assessment'.

Modules The design tools (except stage gate) are split into modules e.g. 'QFD', 'Site Characterisation', 'Energy Capture', 'System RAMS (Reliability Availability Maintainability and Survivability)' (shown in light blue). This follows the terminology of the original DTOcean software.
These each contain multiple functions/processes/routines etc. that perform the calculation/assessment (not shown for clarity).

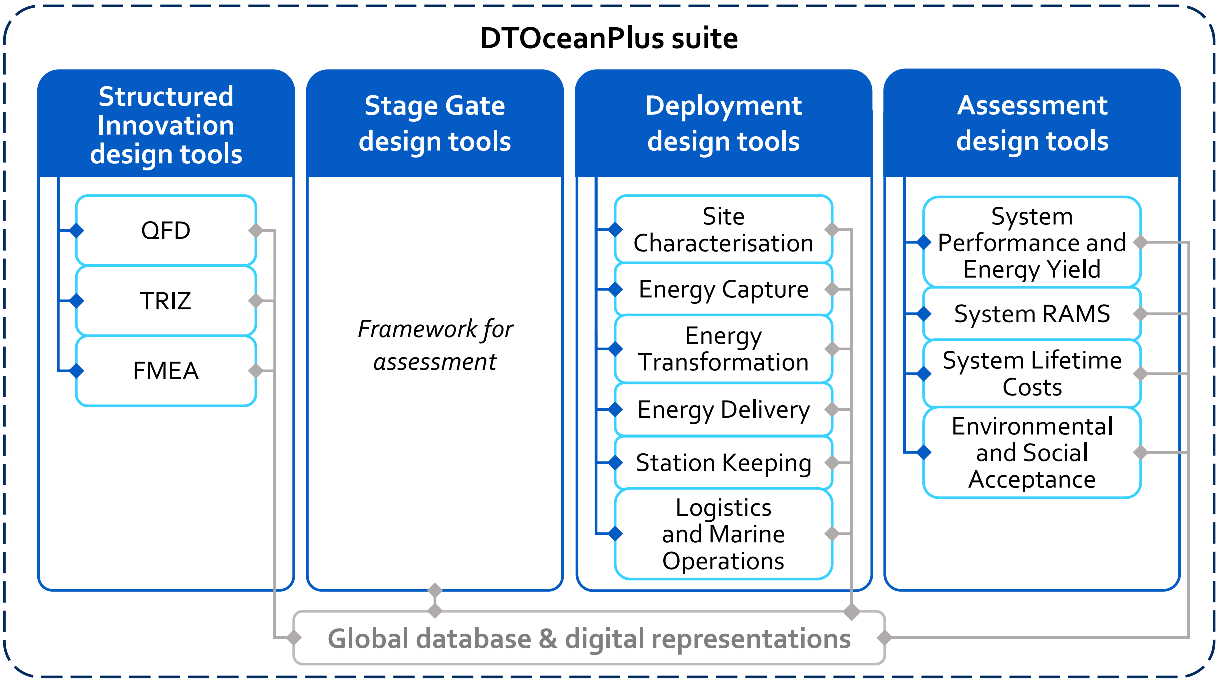

FIGURE 0.1 REPRESENTATION OF THE DTOCEANPLUS TOOLS HIERARCHY

In addition, there are a number of terms with a specific meaning generally or within DTOceanPlus.

Operational Requirements Define the major purpose of a system (i.e. what it fundamentally does; its capability) together with the key overarching constraints. The Operational Requirement(s) is a succinct clear and unambiguous statement as to what the system fundamentally does with the key constraints.

Functional Requirements Specify what the system must do to achieve the Operational Requirements. A Functional Requirement does not define how it is done or how well it is done and should be implementation independent.

Technical requirements Factors that are required to deliver a desired function or behaviour from a system to satisfy a user's standards and needs. Specify how to implement what the system must do in order to get what is required. These include accessibility, adaptability, usability, auditability, maintainability, performance, etc.

Global database A shared database containing input data, the digital representations of components to arrays, and accessed by all of the design tools

Quality Function Deployment (QFD) A structured method used to identify, prioritise customers' requirements and translate them into suitable technical requirements for each stage of product development and production. It is achieved using the House of Quality (HoQ) which is a matrix used to describe the most important product or service attributes or qualities [1].

Theory of Inventive Problem (TRIZ) A systematic problem-solving approach based on universal principles of creativity, patents and research. The module looks to identify the generic concept problems and solutions, and to eliminate the technical and/or physical contradictions.

Failure Modes and Effects Analysis (FMEA) A module used as a risk analysis and mitigation tool to improve development ventures. At concept and design phases, the concept FMEA mitigates risks associated with the various concept selections [2].

Stage Gate Metrics The measures of success which define the performance of a technology. These are strongly linked to the Deployment and Assessment tools which calculate the required metrics.

Stage Gate Metrics Framework The structure which defines what to assess, in what level of detail, and against which benchmarks for success for technologies in a technology development process.

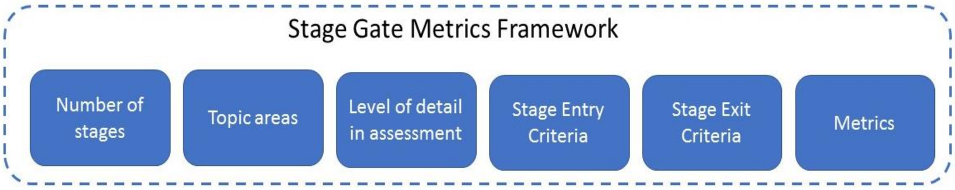

FIGURE 0.2: REPRESENTATION OF A STAGE GATE METRICS FRAMEWORK

Within a stage gate metrics framework, the following is defined:

- Number of stages within the stage gate metrics framework
- Stage entry and stage exit criteria Topic areas: These are a list of the topics which are to be assessed and are linked to the Deployment and Assessment tools. Examples of some of these are: Maintainability, Installability and Energy Capture.
- Level of detail for each stage and topic area: At lower TRL (lower maturity), technologies are likely to have less data supporting their performance and therefore will be assessed at a higher and less detailed level. At higher TRL (higher maturity), there may be more data available and therefore the level of assessment can be more complex and detailed.
- Metrics: The measures of success, these are the measures which define the performance of a technology.

Stage Entry Criteria	Defined activities which have taken place in the development of a technology – but not the results of such activities (i.e. It is not a measure of performance). For example, Entry to Wave Energy Scotland (WES) Stage 2 includes "Numerical models have been completed and validated against tank test data" or "Small scale physical testing is complete in realistic wave conditions".
Stage Exit Criteria	The thresholds of performance which must have been achieved for a technology to "pass" a stage which it is being assessed against. These may be defined by the users of the tool themselves, or they can be selected from a list of default values.
Power Take-Off	The system converting the power captured by the Offshore Energy Converter (OEC) hydrodynamics and converted into useful electrical power. It is composed of at least of prime mover an electrical generator and a power converter.
Annual Energy Production (AEP)	Average annual electricity production, in MWh, of a device or array.
Bill of Materials	List of components, sub-assemblies and/or logistical actions that are associated with a project, technology or sub-system under analysis, with associated quantities
Discount Rate	The discount rate is a measure of time-value, which is the price put on the time that an investor waits for a return on an investment. Furthermore, the discount rate is also used to account for the risks and uncertainties of an investment. It is used for present value calculations.
Capital Expenditure (CAPEX)	Initial costs for setting up a project, including project development, site preparation, procurement, construction and installation.
Internal Rate of Return (IRR)	Discount Rate that sets the net present value of all cash flows at zero. It is the rate at which the project will reach the break-even point at end.
Levelised Cost of Energy (LCOE)	Economic assessment of the energy-generating system costs over its lifetime, accounting for the time-value of money and risk.
Net Present Value (NPV)	Sum of the present values of the individual cash flows of the same entity. It is a measure of the profitability of a project.
Operational Expenditure (OPEX)	All the cost incurred during the operational lifetime of the project.
Payback time	The payback period is the time needed for the project to break even. It can be simple, i.e. not accounting for time-value, or discounted, i.e., using a discount rate.
Present value	The value of a future quantity at the present time, accounting for time-value and risk.
Weighted Average Cost of Capital (WACC)	The rate obtained by combining the rates on investment and/or interest rates of the different financing options, weighted by the contribution to financing.

Receptor	A receptor is the entity that is potentially sensitive to a stressor (see definition of stressor below) related to an ocean energy project. Receptors can be for instance *marine mammals or birds* (sensitive to stressors such as collision risks with vessels or underwater noise due to operation and maintenance); *seabed habitat and associated communities* that can be degraded due to anchoring systems or; *fish and invertebrates* that can be impacted by chemical pollution such as oil or lubricants used by vessels and marine infrastructures. In DTOceanPlus, social acceptance will also be considered as a receptor. Estimating carbon footprint for manufacturing materials, producing energy or operation and maintenance activities can have an impact on *social acceptability*.
Stressor	A stressor is any physical, chemical, or biological entity that can generate a pressure or an environmental/ social impact. Stressors create a pressure on the environment such as *collision risk* (i.e. interaction between wildlife – e.g. mammals and birds – and vessels that may result in physical injuries); *footprint* (i.e. seabed that can be degraded by operation and maintenance activities - e.g. anchoring systems) or *carbon footprint* for manufacturing materials, producing energy or operation and maintenance activities.

1. INTRODUCTION

The DTOceanPlus project will develop an open-source integrated suite of 2nd generation tools for ocean energy technologies [3]. The tools will support the entire technology innovation and advancement process from concept, through development, to deployment, and will be applicable at a range of levels: sub-system, device, and array. The proposed tools are covered in more detail in section 2.1. At a high level, these will include:

- **Structured Innovation Tools**, for concept creation, selection, and design.
- **Stage Gate Tools**, using metrics to measure, assess and guide technology development.
- **Deployment Tools**, supporting optimal device and array deployment.
- **Assessment Tools**, used by the other tools to quantify key parameters.

1.1 SCOPE OF REPORT

This report is the outcome of Task 2.2 'Analysis of tool requirements and best practices', to translate stakeholder needs into a coherent set of detailed requirements (functional, operational, user, interfacing, and data) for the DTOceanPlus software. Building on this, detailed specifications for the software tool development will be produced in tasks T3.1, T4.1, T5.1, T6.1, and T7.1 of work packages 3–7, as shown in figure 1.1.

In order to focus the development effort to best meet the needs of the industry, a gap analysis was conducted as part of T2.2 to understand discrepancies between the current state-of-the-art tools (including the original DTOcean software) and the stakeholder expectations identified in the user consultation exercise, T2.1.

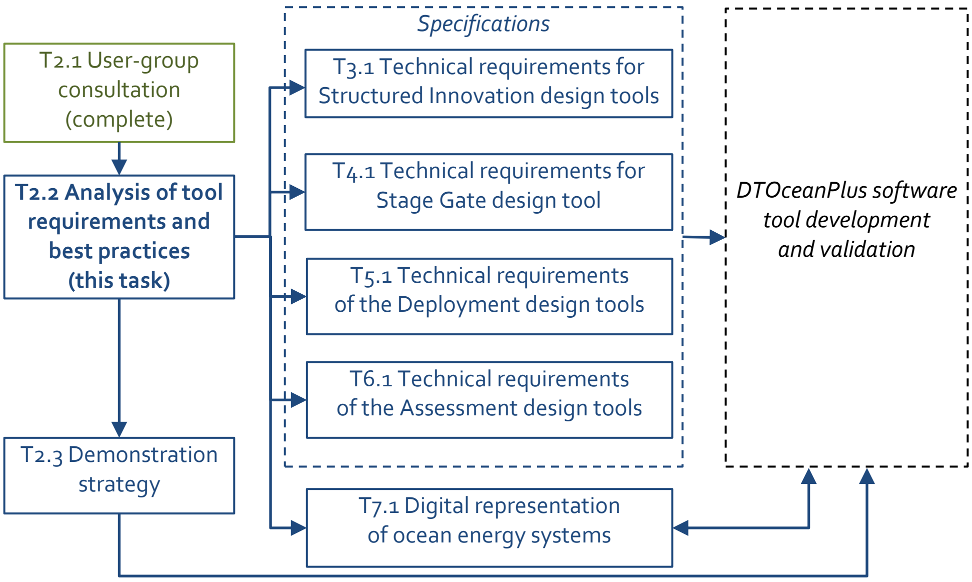

FIGURE 1.1: GRAPHICAL SUMMARY OF SOFTWARE SPECIFICATION TASKS (EXTRACTED FROM GRAPHICAL PRESENTATION OF THE PROJECT [4])

1.2 OUTLINE OF REPORT

This report specifies the detailed requirements (functional, operational, user, interfacing, and data) for the DTOceanPlus suite of tools, to act as specifications for tool development work packages WP 3, 4, 5, and 6.

The remainder of the report is laid out as follows:

- Section 1.3 summarises the original DTOcean software and other tools for the assessment of ocean energy, representing the current state-of-the-art. Feedback from the user needs consultation is then summarised in section 1.4
- Section 2 covers the scope of the proposed DTOceanPlus suite of design tools, along with general requirements for the DTOceanPlus software including pre-requisites for the tools.
- Section 3, the Structured Innovation design tools which will be developed in WP3
- Section **¡Error! No se encuentra el origen de la referencia.**, the Stage Gate design tools developed in WP4
- Section 5, the Deployment design tools (WP5, split by task for individual modules)
- Section 6, the Assessment design tools (WP6, split by task for individual modules)
- Finally, section 7 gives conclusions and summarises the next steps.

The requirements outlined in sections 3–6 for each of the design tools are handled in a consistent manner, with minor adaptations to the specifics of different tools. In each section, there is an outline of those design tools, a summary of user requirements, how the design tools will be applied at different levels of complexity, data requirements and internal/external interfaces, plus any key limitations or exclusions.

An accompanying technical note (TN2.2 [5]) collates annexes of detailed analysis of the user requirements for different tools (for DTOceanPlus partners only).

1.3 CURRENT STATE-OF-THE-ART AND EXISTING TOOLS

This section reviews existing tools for the design of ocean energy technologies, including the original DTOcean project. The state-of-the-art for the novel Structured Innovation and Stage Gate design tools is outlined in sections 3.1 and 4.1 respectively.

The original DTOcean project developed a suite of tools for the design of wave and tidal energy arrays. Given details of a site and energy capture device, DTOcean provides optimal designs for array Balance of Plant, as summarised in section 1.3.1. This project ran between 2013 and 2016, and was funded under the EU FP7 framework Grant Agreement № 60859 [1].

Although other design tools for ocean energy arrays exist (e.g. Exceedence Finance or Wave Venture TE), DTOcean is considered state-of-the-art in this field. While the alternative design tools mentioned focus heavily on techno-economic and financial analysis, DTOcean is the only tool to our knowledge for both tidal and wave energy technologies that provides array designs and has global optimisation capabilities and lifecycle performance indicators (key metrics of cost, reliability, and environmental impact).

Design tools for a great many specific applications in ocean energy exist and are in widespread use in the sector. Examples include OrcaFlex for the design of moorings solutions, ForeCoast Marine for the design of O&M procedures, and WEC-Sim for the design of wave energy devices. These design tools focus on a specific scientific theme with high computing costs for refined models of detailed engineering stages. Capabilities of other key programs are summarised in section 1.3.2.

Functionality desired by potential users of DTOceanPlus over-and-above this state-of-the-art was addressed as part of deliverable D2.1 User Needs Consultation [6]. This has been reviewed, with the most relevant topics extracted for each of the design tools being covered in sections 3–6 of this report.

1.3.1 SUMMARY OF DTOCEAN SOFTWARE

The original DTOcean Project[1] produced a first generation of freely-available open-source design tools for wave and tidal energy arrays. The project built an integrated suite of tools [7] split into five modules or stages:

- **Hydrodynamics**: designs the layout of converters in a chosen region and calculates their power output.
- **Electrical sub-systems**: designs an electrical layout for the given converter locations and calculates the electrical energy exported to shore.
- **Moorings and foundations**: designs the foundations and moorings required to secure the converters at their given locations.
- **Installation**: designs the installation plan for the energy converters and the components required to satisfy the electrical sub-system and moorings and foundations designs.
- **Operations and maintenance**: calculates the required maintenance actions and power losses resulting from the operation of the converters over the lifetime of the array.

These were brought together by a global decision tool containing optimisation routines, as shown in Figure 1.2. These routines can evaluate each stage of the design, and the design as a whole, using three thematic assessments:

- **Economics**: produces economic indicators for the design, in particular the Levelised Cost of Energy (LCOE).
- **Reliability**: assesses the reliability of the components in the design over the array lifetime.
- **Environmental**: assesses the environmental impact of each stage of the design.

The original DTOcean suite of tools is currently considered to be at TRL 4, having been validated in a research (laboratory) setting. The H2020 project Enabling Future Arrays in Tidal (EnFAIT)[2], Grant Agreement № 745862, will carry out a demonstration of a grid-connected tidal energy array with the aim to provide a step change in the lifetime cost of energy for tidal power. The project plans to adjust the layout of the turbines in order to enable array interactions and optimisation to be studied for the first time at a real tidal energy site [8].

[1] http://www.dtocean.eu/
[2] www.enfait.eu

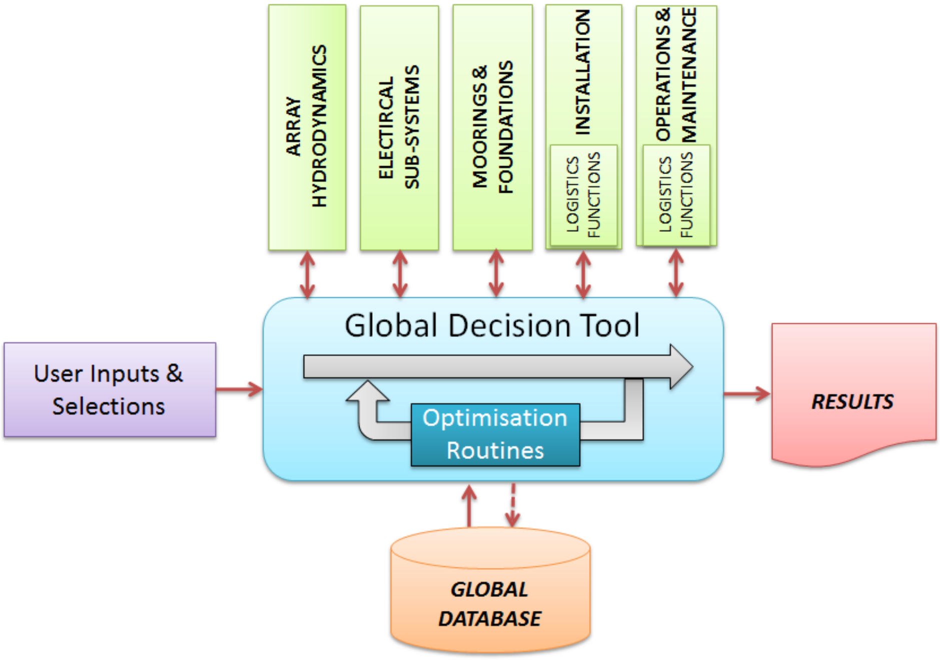

FIGURE 1.2: FUNCTIONAL STRUCTURE OF ORIGINAL DTOCEAN SOFTWARE [7]

One of the purposes of EnFAIT Work Package 10 is to validate the capabilities of the array modelling tool. The capability assessment compares the original DTOcean tools against the real-world tidal energy array. The aim of this comparison is to provide a baseline validation of DTOcean with insights gained from the design decisions made by Nova Innovation in deploying an existing array. Deliverable D10.3 [9], which is available for public dissemination, shows the outcomes of the first evaluation. The objective is to highlight areas for further investigations and improvement for the numerical model.

EnFAIT deliverable D10.3 focuses on the analysis of hydrodynamic, electrical, mooring and foundation modules and economic assessment. Results show that in general, the hydrodynamic module presents a medium level of similarity between numerical outputs and existing array. The moorings and foundations module also presents a medium level of accuracy when compared to the existing array. The weakest module appears to be the electrical one, as the results do not match the choices taken in the existing array. Finally, the economic assessment presents a good level of accuracy in general terms. In most of the cases, the divergence of results between DTOcean and the existing array are due to DTOcean focusing on fully commercial arrays, which differ from early stage arrays like that being developed by Nova Innovation in the EnFAIT project.

The EnFAIT project is continuing to demonstrate and validate the DTOcean toolset, moving it towards TRL 5, and the DTOceanPlus project will build on this. It is noted that Nova Innovation are also a partner within DTOceanPlus, and thus the demonstration scenarios discussed in section 2.3.1 will likewise build on this work.

1.3.2 OTHER TOOLS FOR THE ASSESSMENT OF OCEAN ENERGY

There is a wide range of other software tools and products that can be used for the assessment of ocean energy, features from a selection of which are summarised below. The competitive landscape for ocean energy design tools can broadly be divided in to three categories:

1. **Freely available software** (e.g. WEC-Sim and NEMOH). All such packages identified here focus on a particular phase of the design process (e.g. optimisation of device energy capture) or a particular technology (i.e. wave or tidal). DTOceanPlus will provide a single, integrated solution to support the entire innovation and development process for wave and tidal sub-systems, devices, and arrays.
2. **Commercial packages** (e.g. DNV GL WaveFarmer and TidalFarmer). Such packages come at considerable cost and cannot be readily tailored to meet the specific needs of a given user. DTOceanPlus will overcome both limitations by developing free and open-source software.
3. **Financial packages** (e.g. Exeedence Finance). Financial analysis packages for ocean energy technologies focus on assessing and optimising the cost efficiency of deployed ocean energy technologies. Lifetime cost is just one of the nine essential metrics that DTOceanPlus will allow assessment and optimisation against, the others being system performance, energy yield, reliability, availability, maintainability, survivability, social acceptability, and environmental acceptability.

A non-exhaustive list of other software packages that duplicate (parts of) the functionality proposed for DTOceanPlus is presented in table 1.1, table 1.2, and table 1.3.

TABLE 1.1: OTHER FREELY AVAILABLE SOFTWARE FOR DESIGN OF OCEAN ENERGY SYSTEMS

Name & (Developer)	Summary/key functionality & website
Edinburgh Wave Systems Toolbox (Dr Richard Crozier, University of Edinburgh)	The Edinburgh Wave Systems Simulation Toolbox is a new toolbox primarily designed for the simulation of wave energy converters. The toolbox also contains more general-purpose components useful for simulating a wide range of systems, including electrical machines, hydraulics, advanced multibody dynamics and wave interaction. The simulation system is also optimised for batch processing and optimisation tasks run on servers. The code is based in Matlab, but also capable of running in the free alternative, Octave. [10] https://sourceforge.net/projects/rnfoundry/
NEMOH (LHEEA, Ecole Centrale de Nantes)	NEMOH is a Boundary Element Methods (BEM) code dedicated to the computation of first order wave loads on offshore structures (added mass, radiation damping, and diffraction forces). Unlike other BEM software, NEMOH's approach decouples the resolution of the linear free surface boundary value problem and the definition of the boundary condition on the body (body condition). This feature makes it easy to deal with flexible structure, hydro-elasticity, generalised modes and unconventional degrees of freedom. [11] https://lheea.ec-nantes.fr/software-and-patents/nemoh-presentation-217691.kjsp

Name & (Developer)	Summary/key functionality & website
OpenFOAM (OpenCFD)	OpenFOAM (for "Open source Field Operation And Manipulation") is a C++ toolbox for the development of customised numerical solvers, and pre-/post-processing utilities for the solution of continuum mechanics problems, including computational fluid dynamics (CFD). [12] https://www.openfoam.com/
SWAN (TU Delft)	SWAN (Simulating WAves Nearshore) is a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters. SWAN accounts for the following physics: Wave propagation in time and space, shoaling, refraction due to current and depth, frequency shifting due to currents and non-stationary depth; Wave generation by wind. Three- and four-wave interactions; Whitecapping, bottom friction and depth-induced breaking; Dissipation due to aquatic vegetation, turbulent flow and viscous fluid mud; Wave-induced set-up; Propagation from laboratory up to global scales; Transmission through and reflection (specular and diffuse) against obstacles; and Diffraction. [13] http://swanmodel.sourceforge.net/
Telemac-Mascaret (Open Telemac-Mascaret Consortium)	An integrated suite of solvers for use in the field of free-surface flow, including: MASCARET for one-dimensional flows; TELEMAC-2D for two-dimensional flows (Saint-Venant equations); TELEMAC-3D for three-dimensional flows (Navier-Stokes equations); and TOMAWAC for wave propagation in the coastal zone. [14] http://www.opentelemac.org/
Wave Energy Scotland O&M tool † (Dr Anthony Grey, IDCORE)	The tool has been created using Microsoft Excel and the associated VBA programming language. It uses the Monte Carlo method to simulate the occurrence of faults on each WEC in an array by utilising failure rate data. All the components of the device are represented by fault categories, assigned following a Failure Modes and Effects Analysis (FMEA) of the device. [15] https://library.waveenergyscotland.co.uk/other-activities/om-simulation-tool/
WAVEWATCH III (NOAA/NCEP)	WAVEWATCH III® is a third-generation wave model developed at NOAA/NCEP in the spirit of the WAM model. WAVEWATCH III® solves the random phase spectral action density balance equation for wavenumber-direction spectra. The implicit assumption of this equation is that properties of medium (water depth and current) as well as the wave field itself vary on time and space scales that are much larger than the variation scales of a single wave. Some source term options for extremely shallow water (surf zone) have been included, as well as wetting and drying of grid points. Whereas the surf-zone physics implemented so far are still fairly rudimentary, it does imply that the wave model can now be applied to arbitrary shallow water. [16] http://polar.ncep.noaa.gov/waves/wavewatch/
WEC-Sim † (Sandia/NREL)	A wave energy converter simulation tool. The code is developed in MATLAB/SIMULINK using the multi-body dynamics solver Simscape Multibody. WEC-Sim has the ability to model devices that are comprised of rigid bodies, power-take-off systems, and mooring systems. Simulations are performed in the time-domain by solving the governing WEC equations of motion in 6 degrees-of-freedom. [17] https://wec-sim.github.io/WEC-Sim/
† Note, free open-source software, but runs in a commercial, closed-source programme.	

TABLE 1.2: COMMERCIAL SOFTWARE PACKAGES FOR DESIGN OF OCEAN ENERGY SYSTEMS

Name & (Developer)	Key functionality
ANSYS Aqwa (ANSYS)	ANSYS Aqwa software addresses the vast majority of analysis requirements associated with hydrodynamic assessment of all types of offshore and marine structures. ANSYS Aqwa Diffraction provides an integrated facility for developing primary hydrodynamic parameters required to undertake complex motions and response analysis. ANSYS Aqwa Suite extends this to include analysis capabilities for global performance of moored and/or connected systems subject to random sea states. Simulations may be static or dynamic in frequency and/or time domain. More advanced requirements, such as dynamic position systems and energy dissipation, can be accomplished through a user-defined function. [18] https://www.ansys.com/en-gb/products/structures/ansys-aqwa
ANSYS Fluent (ANSYS)	ANSYS Fluent software is a powerful computational fluid dynamics (CFD) tool. It contains the broad physical modelling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applications—ranging from air flow over an aircraft wing to combustion in a furnace, from bubble columns to oil platforms, from blood flow to semiconductor manufacturing, and from clean room design to wastewater treatment plants. Fluent covers a broad reach, including special models with capabilities to model in-cylinder combustion, aero-acoustics, turbo-machinery and multiphase systems. [19] https://www.ansys.com/en-gb/products/fluids/ansys-fluent
Ariane (Bureau Veritas)	Ariane is an efficient static / time-domain multi-body mooring software developed by Bureau Veritas. Ariane benefits from thirty-years of development and gathers together BV's extensive expertise and knowledge in hydrodynamic and mooring fields. The user is now able to study more complex mooring systems such as side-by-side or jetty mooring with more accuracy. In particular, the user is now free to calculate the 6 degree of freedom motions of the floating bodies and to use coupled calculations between low and wave frequencies. An optional Dynamic Positioning module enlarges simulations capabilities computing static and time-domain responses of fully user defined DP systems. [20] https://www.veristar.com/portal/veristarinfo/detail/software/Seakeeping%20and%20Mooring%20Analysis/ARIANE/moor
DeepLines (Principia)	DeepLines is based on the finite elements method and forms an integrated software solution to perform in-place and installation analyses of a wide range of offshore structures. The software package comprises a powerful finite elements engine featuring advanced modelling capabilities and an intuitive graphical user interface offering optimum productivity through multi-tasking. Key applications include design of flexible and steel risers, power cables and umbilical, pipelines, mooring systems, towed systems, renewable energy systems and simulation of marine operations. [21] http://www.principia-group.com/blog/product/produit-deeplines/
Flexcom Wave (Wood)	An offshore marine simulator for hydrodynamic modelling, and structural analysis based on finite element simulation. Flexcom is capable of simulating: Risers; Mooring lines; Umbilicals; Floating bodies; Offloading lines; Seafloor conduits; Installation processes; Renewable energy devices such as wave energy converters and floating offshore wind turbines. [22] https://www.woodgroup.com/flexcom
Flow-3D (Flow Science Inc.)	FLOW-3D is a highly-accurate CFD software that specialises in solving transient, free-surface problems. https://www.flow3d.com/products/flow-3d/

Name & (Developer)	Key functionality
ForeCoast Marine (Jeremy Benn Associates)	Advanced metocean risk management software, allowing you to manage weather downtime across the lifecycle of your marine development: from pricing weather into tenders, to designing construction and O&M strategies, to managing live weather risks. Bring weather forecasts, wave buoy and operational data together into one digital platform, so that more informed and efficient decisions can be made. Web-based, so you can access it on your PC or mobile device. [23] https://www.forecoastmarine.com/
HYDROSTAR (Bureau Veritas)	HydroSTAR is the state-of-the-art hydrodynamic software developed by Bureau Veritas to evaluate 1st & 2nd order wave loads and induced motions of one or several ships or marine structures of any type in deep and finite water depth. It benefits from more than 20 years of development and it is continuously updated and improved to rise to technological challenges. [24] https://www.veristar.com/portal/veristarinfo/detail/downloads/Calculation%20Software/hydrostar
Mermaid (Mojo Maritime/ James Fisher)	A marine economic risk management aid. Mermaid is a sophisticated marine operations and analysis system that quantifies weather risk by forecasting its impact on simulated project plans. The system allows marine contractors to optimise plans through accurate modelling and scenario planning, enabling significant cost reductions and project optimisation. Mermaid uses historic hind-cast weather data for specific project sites to precisely quantify the weather risk and therefore determine the optimal and risk-minimised weather window for your project. By using hind-cast data instead of averaged theoretical weather, Mermaid is uniquely accurate in its predictions. [25] https://www.james-fisher.com/services/marine-services/mermaid/
MIKE21 (DHI)	MIKE 21 is a leading software package for 2D modelling of hydrodynamics, waves, sediment dynamics, water quality, and ecology. Also includes a mooring analysis module. https://www.mikepoweredbydhi.com/products/mike-21
MIKE3 (DHI)	MIKE 3 provides the simulation tools you need to model 3D free surface flows, using either a single grid, multiple dynamically nested grids, or a flexible mesh. https://www.mikepoweredbydhi.com/products/mike-3
OrcaFlex (Orcina)	OrcaFlex is a leading package for the dynamic analysis of offshore marine systems such as risers and moorings. https://www.orcina.com/SoftwareProducts/OrcaFlex/
TidalBladed (DNV GL)	Tidal bladed is an industry-standard tidal turbine modelling software for horizontal axis tidal stream turbines. It helps you design all the main components in a single software platform, including: Sub structure; Drive train; Support structure; Blades; Blade orientation; & Control strategy. You can optimise your design for a specific project, while the tool can also be used to describe the environment of the specific project location. It also gives you site-specific performance, load characteristics and calculations. [26] https://www.dnvgl.com/services/tidalbladed-3799
TidalFarmer (DNV GL)	A 3D array modelling tool built on validated wake models that capture wake mixing processes downstream of tidal power devices. It combines these models with survey measurements, site-specific constraints, description of the tidal device and local bathymetry. Based on this bespoke input, it enables you to generate: Resource assessments; Accurate energy yields; and Array-generated wake maps. [27] https://www.dnvgl.com/services/tidalfarmer-3774

Name & (Developer)	Key functionality
WAMIT (WAMIT, Inc.)	WAMIT is a computer program based on the linear and second-order potential theory for analysing floating or submerged bodies, in the presence of ocean waves. The boundary integral equation method (BIEM), also known as the panel method, is used to solve for the velocity potential and fluid pressure on the submerged surfaces of the bodies. Separate solutions are carried out simultaneously for the diffraction problem, giving the effects of incident waves on the body, and the radiation problems for each of the prescribed modes of motion of the bodies. These solutions are then used to obtain the relevant hydrodynamic parameters including added-mass and damping coefficients, exciting forces, response-amplitude operators (RAO's), the pressure and fluid velocity, and the mean drift forces and moments. The second-order module, Version 6S, provides complete second-order nonlinear quantities in addition. [28] https://www.wamit.com/
WaveDyn (DNV GL)	The first fully coupled simulation tool designed for wave energy. It allows you to simulate the performance and loading on a wave energy device. It enables you to model hydrodynamics calculations, and control and power take-off systems. [29] https://www.dnvgl.com/services/wavedyn-3800
WaveFarmer (DNV GL)	It enables you to calculate and analyse a wave farm array's electricity output. You can use WaveFarmer to: Assess a project's economic feasibility; Optimise the array design for maximum yield; Confirm yield predictions supplied by other parties; and Ensure the final array design meets all pre-defined constraints [30] https://www.dnvgl.com/services/wavefarmer-3772

TABLE 1.3: FINANCIAL SOFTWARE PACKAGES FOR OCEAN ENERGY SYSTEMS

Name & (Developer)	Key functionality
Exceedence Finance (Exceedence)	Providing techno-commercial evaluations of Wind, Offshore Wind, Wave, Tidal projects, and Combined Platform technologies. Exceedence software provides an easy like-for-like comparison across devices, projects and locations with the bottom line being financial viability. Indicators such as Levelised Cost of Electricity (LCOE), Internal Rate of Return (IRR), Net Present Value (NPV), Payback and Cash flows are provided to answer these questions. [31] https://exceedence.com/
Optiwave (Wood/Exceedance)	A financial and engineering optimisation software platform which combines Exceedence Finance and Flexcom Wave. (see above for details) https://www.woodgroup.com/optiwave
Wave Venture TE (Ocean Wave Venture Ltd)	Wave Venture TE is an integrated techno-economic analysis software specifically designed for optimising the commercial performance of wave energy conversion systems. This software currently underpins many of our consultancy service offerings and we are investing in further development towards a software release. Wave Venture provides a standardised general-purpose software tool for WEC performance assessment and optimisation. The components of this tool are: engineering analysis; operational simulation; financial analysis; and numerical optimisation. [32] http://www.wave-venture.com/software/

1.4 SUMMARY OF USER NEEDS CONSULTATION

A consultation to understand the needs of potential DTOceanPlus users was conducted in summer 2018, with the results published in Deliverable D2.1 Results from user consultation [6]. This report presents findings from a consultation of potential users and other stakeholders for the DTOceanPlus tools, to identify and clarify their needs and requirements. Opinions from over 70 industry professionals from a wide range of backgrounds were collated and analysed. These have been used to inform the functional requirements for the development of the DTOceanPlus tools and software.

Further work is required during the DTOceanPlus project to explain the functionality and use of the proposed tools, particularly focusing on the Structured Innovation concept as this is less well understood. Additional clarification of the tool's scope would also be beneficial, in terms of stages of the development lifecycle covered, how this links with TRL, and to different points during a project.

Of the overall software characteristics considered, usability followed by flexibility & expandability then modularity were seen as most important. Additionally, transparency of how the tools work is critical, including documentation referenced to background research, and some form of version control or parameter tracking. A high-quality software product is expected of DTOceanPlus, something not all people consider DTOcean to have delivered.

The proposed tools will need to address varying degrees of complexity, both at different stages in the project lifecycle and for different user requirements. How this will be addressed was a concern for some. A suggestion was to have 'high-level' and 'technical' tools (or 'simple' and 'expert' modes), exposing more detail in the latter for those who have data and time available to do more analysis.

Several responses stressed the importance of linkages between the tools, and with external software. One technology developer suggested having an application programming interface (API) to allow external software and scripts two-way access to the DTOceanPlus tools and data, allowing flexibility to use either DTOceanPlus or another tool as deemed most appropriate.

Nearly all respondents (>85%) indicated that they were likely or very likely to use DTOceanPlus at some stage in the project lifecycle. Similarly, most (>80%) responded that they understood or somewhat understood conceptually what all the DTOceanPlus tools would do.

Specific interpretation of how the user requirements from the consultation apply to each of the design tools is included within the relevant requirements sections in the remainder of this report.

2. DTOCEANPLUS

2.1 THE DTOCEANPLUS DESIGN TOOLS

2.1.1 SUMMARY OF THE DESIGN TOOLS

The DTOceanPlus software will comprise a number of 2nd generation design tools, which are summarised below and illustrated at a high level in figure 2.1. The Structured Innovation and Stage Gate design tools are new to DTOceanPlus, with the Deployment and Assessment Design Tools significantly improved from the original DTOcean versions. The suite of design tools will be designed to assess various levels of complexity and be used throughout the project lifecycle.

- **Structured Innovation Design Tools**, for concept creation, selection, and design, with three modules:
  - Quality Function Deployment (QFD),
  - TRIZ (Theory of Inventive Problem Solving), and
  - Failure Modes and Effects Analysis (FMEA).
- **Stage Gate Design Tools**, using metrics to measure, assess and guide technology development. As part of this, the DTOceanPlus project will develop:
  - A stage-gate structure.
  - Metrics and success thresholds.
  - Tools for measuring success and analysing performance against metrics and thresholds.
  - Stage gates and metrics graded to the relevant stage in through the technology development process.
- **Deployment Design Tools**, supporting optimal device and array deployment. These will improve and expand on the capabilities of the original DTOcean software to consider the main functionalities of ocean energy technologies and systems, split into six modules:
  - Site Characterisation (e.g. metocean, geotechnical, and environmental conditions), a new module within DTOceanPlus.
  - Energy Capture at an array level.
  - Energy Transformation (PTO and control), also a new module within DTOceanPlus.
  - Energy Delivery (electrical and grid issues).
  - Station Keeping (moorings and foundations).
  - Logistics and Marine Operations (installation, operation, maintenance, and decommissioning), with expanded scope beyond just O&M in DTOcean.
- **Assessment Design Tools**, will provide objective information to the developer or investor on the suitability of a technology and project, and will also support the other DTOceanPlus design tools, split into four modules:
  - System Performance and Energy Yield.
  - System Lifetime Costs.
  - System Reliability, Availability, Maintainability, Survivability (RAMS), with significantly expanded scope beyond just reliability in DTOcean.

- Environmental and Social Acceptance, with expanded scope from DTOcean to also include social aspects.
- Underlying these will be **common digital models** and a **global database**.
  - These will provide a standard framework for the description of sub-systems, devices and arrays.
  - As well as being a communication method for the various tools, this will provide a common language for the entire sector

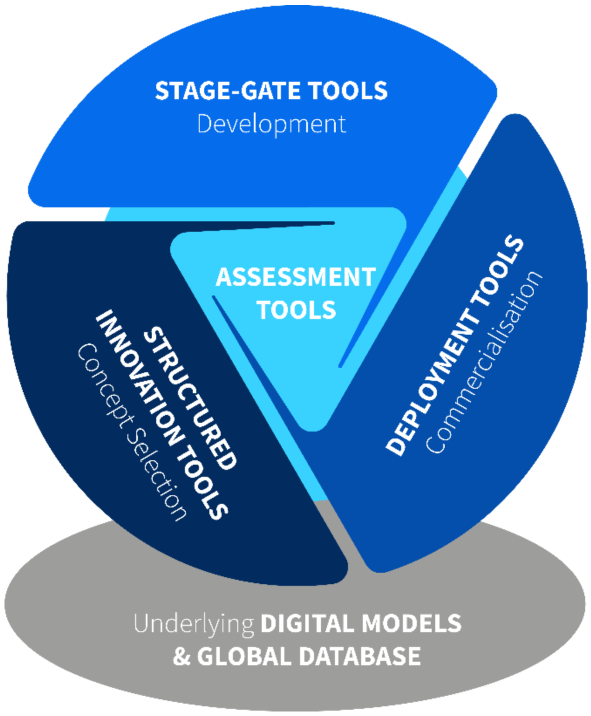

FIGURE 2.1: REPRESENTATION OF DTOCEANPLUS TOOLS

2.1.2 USE AT DIFFERENT LEVELS OF COMPLEXITY

DTOceanPlus will support the development of ocean energy technologies at all stages of the project lifecycle — from concept creation through design development to commercial deployment — with increasing level of data available and detail required at each. It will also be designed to support users with differing requirements in terms of detail; from investors wishing for a high-level overview of a technology or project, to developers performing detailed technical assessments.

The project lifecycle can be seen from two complementary perspectives:

- The chronological phases of a project: namely conception, design, procurement, construction, installation, operation (including maintenance) and decommissioning.
- The project development and/or the technology considered to be deployed can also be split into three stages for clarity (Early, Mid, and Late), as described in Table 2.1. These can broadly be linked to the widely-used TRL scale. Those three stages address all the phases described above, with different levels of complexity accounted for in the project definition.

TABLE 2.1: INDICATIVE STAGES OF PROJECT DEVELOPMENT LINKED TO TRL AND DEVELOPMENT PROGRESS USED WHEN DEFINING DTOCEANPLUS REQUIREMENTS.

Stage	Approx. TRL	Development progress	Description
Early	1-3	Concept definition	Early stage analysis of potential device or site. Gives an overview of capabilities and next development steps, but may be based on limited data.
Mid	4-6	Feasibility	Includes an in-depth study of the topics covered in the concept definition. More accurate than previous stage, with additional data requirements.
Late	7-9	Design and deployment	Key project features are planned in this stage, informed by the previous phases. Makes use of detailed information about the project.
Note that while three stages are shown here to guide the functional requirements and ensure the varying level of complexity throughout the project lifecycle is being addressed appropriately, the number and scope of stages used in DTOceanPlus will be configurable by the user as required.			

As well as being used at different stages in the project development lifecycle, DTOceanPlus will also be applicable to three different levels of technology, specifically:

- **Sub-system**, e.g. PTO, or moorings and foundations that form part of a device.
- **Device**, i.e. one complete system that can be deployed individually or to make up an array.
- **Array** of multiple devices deployed in a farm.

The design tools will not be designed to assess technologies at a component level, although the digital representation may include detail at the component level where available.

The design tools within the DTOceanPlus suite can be summarised as follows:

- The Structured Innovation design tools generates new concepts; including novel concepts for wave and tidal energy devices, or an improvement of a sub-system, device, or array at higher maturity level. The Structured Innovation design tools also provide the ability to assess technologies at the early concept stages when there is minimal data available and will inform part of the inputs for the Stage Gate design tool.
- The Stage Gate design tool supports the objective assessment of technologies in the development process, ensuring a fair assessment of sub-systems, devices and arrays from early stage concepts up to commercial deployment.
- Finally, the Deployment and Assessment design tools execute the key calculations to measure the vital parameters at all stages of the project lifecycle, and ultimately support the Stage Gate design tool by delivering these fundamental computations.

Therefore, an important functionality of DTOceanPlus is the ability assess the performance of technologies throughout the project lifecycle, as a technology matures; when there is less data and information available about a technology at the concept definition stage, and more data from testing and simulations at the design and deployment stage. Table 2.2 below outlines how the assessment method changes through these different stages, depending on the data available, and introduces the terminology of 'fundamental', 'basic', and 'advanced' modes for the tools which will compute the assessments at each of these stages. This assessment is a key functional requirement of the software, and will have consistency in the approach through integration of the tools provided by the Digital Representation. As a running theme throughout the project lifecycle, assessment of sub-systems, devices and arrays must be flexible to the users' requirements depending on the particular user type, the maturity of the technology and the amount of data available. This is highlighted in the use cases described in section 2.2.

TABLE 2.2: INCREASING TOOL COMPLEXITY FOR DIFFERENT DEVELOPMENT STAGES

Stage & approx.TRL	Data availability	Assessment method	Tool description
Early stage (TRL 1–3)	Little quantitative data available; overview of capabilities and operating modes	Assessment through the Structured Innovation and Stage Gate design tools by utilising the earliest level assessments of technologies; these may use: ▫ Fundamental physics, engineering and economic relationships. ▫ Simple, high level quantitative assessments from the Assessment and Deployment design tools. ▫ Scoring of a technology by qualitative assessment from an expert assessor.	Fundamental
Mid stage (TRL 4–6)	Low complexity; limited data available	Simple, high level 'basic' quantitative assessments through the Deployment and Assessment design tools. These can be the same as the detailed 'advanced' tools but with simple parameters and/or default values used.	Basic mode(s)
Late stage (TRL 7-9)	Full complexity; makes use of detailed information about the project.	Detailed 'advanced' quantitative assessments through the Deployment and Assessment design tools.	Advanced mode

2.1.3 NEW TOOLS FOR STRUCTURED INNOVATION AND STAGE GATES

As noted above, significant additions to DTOceanPlus over the original DTOcean software are the Structured Innovation and Stage Gate design tools. These will be based on the best practices from the ocean energy and other sectors, providing a structured method for concept creation and assessing the progress of technology development through defined stages and stage gates. Details of the functional requirements of these tools can be seen in sections 3 and 4 respectively.

2.1.4 IMPROVED DEPLOYMENT AND ASSESSMENT TOOLS

While the first generation of DTOcean tools were validated using what was considered realistic data, it is only now that real-world data from the first wave and tidal energy arrays is available for thorough system validation. DTOceanPlus will enhance the original DTOcean tools to provide a second generation that takes into consideration all lessons learnt from this new validation programme. The DTOceanPlus Consortium is uniquely placed to perform this activity as it includes stakeholders in key array deployments.

Furthermore, the ocean energy sector has evolved greatly since the inception of the first generation of DTOcean tools and enhancements will be made to ensure that the second generation of tools meet the needs of the sector in its current form and for years to come. The needs of prospective users and other key stakeholders were assessed via a consultation exercise in summer 2018, to identify and prioritise the requirements for DTOceanPlus.

The improved Deployment and Assessment Design Tools are covered in more detail in sections 5 and 6, however key upgrades from the original DTOcean software include:

- Standard data models will be adopted and adapted to represent ocean energy systems, including sub-systems, devices, and arrays. By way of example, the Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a construction project. This is discussed in more detail in section 0.
- Two new design modules have been added to increase the capability of the DTOceanPlus suite:
    1. The Energy Transformation design tools, which will be used to select appropriate Power Take-Off (PTO) solutions and suitable device control strategies;
    2. The Site Characterisation design tools, to provide a first stage of resource modelling across a deployment site, integrating the open-source Telemac-Mascaret tools.
- There will also be upgrades to the run time, design accuracy, parameter sensitivity, management of uncertainties, usability, modularity, and optimisation of all existing DTOcean tools, including those for energy capture, energy delivery, station-keeping, logistics, operations & maintenance.
- Higher fidelity assessment of lifetime costs, reliability, and environmental impact will be provided along with additional assessment of performance, energy yield, availability, maintainability, survivability, and social acceptance.

As with all other tools in the DTOceanPlus suite, the Deployment and Assessment design tools will be validated and demonstrated within the project to take them to TRL 6, with the technology validated and demonstrated in a relevant environment. The methodology for the demonstration cases will be defined in task T2.3, with the assessment undertaken in T7.4 and T7.5 towards the end of the project.

The final DTOceanPlus suite of tools will provide a single, integrated solution for the design of all levels of ocean energy technology (from sub-systems, to devices and arrays) and across all stages (from concept, to development and deployment). It will assist users in working towards an optimal solution based on information available at a particular stage.

2.2 EXAMPLE USE CASES

As discussed above, the DTOceanPlus suite consists of three types of design tools:

1. **Structured Innovation Design Tools** – *for creating concepts and ideas.*
2. **Stage Gate Design Tools** – *a framework to support decision making.*
3. **Deployment and Assessment Design Tools** – *for calculating parameters/metrics.*

The predominant users of DTOceanPlus can also be split into three main categories:

1. **Technology Developers** – *focusing on developing their specific device/technology.*
2. **Project Developers** – *focusing on deploying devices/arrays commercially.*
3. **Public & Private Investors** – with largely overlapping requirements of *understanding financial implications in support of the first two users and development of the sector*

Other users, such as certification bodies or academics, will largely be acting in one or more of these capacities. It is acknowledged that this list of user types does not fully cover the full complexity of all those who may use DTOceanPlus, but it offers a useful illustrative simplification. The assessment design tools also support the assessments made in the other tools and modules.

A 3×3 matrix of users and tools is shown in table 2.3, illustrating the process of identifying interlinking use cases (UC). A total of 43 example use cases are presented in the following sections, although it is noted this list is not exhaustive. The links between these use cases are then shown graphically in figure 2.2.

TABLE 2.3: USERS AND TOOLS FOR EXAMPLE USE CASES

Tools: / Users	Structured Innovation design tools	Stage Gate design tools	Deployment and Assessment design tools
Technology Developers	▫ Use case, UC1.1 ▫ UC1.2	▫ UC2.1 ▫ UC2.2	▫ UC3.1 ▫ …
Project Developers	▫ UC4.1 ▫ UC4.2	▫ UC5.1 ▫ …	
Public & Private Investors	▫ UC7.1 ▫ …		▫ Etc.

2.2.1 TECHNOLOGY DEVELOPERS

UC1. Technology Developers using Structured Innovation design tools

UC1.1. Creating new or improving a device concept [links to UC1.2, UC1.3, UC2.4, UC7.1, UC7.2]
UC1.2. Creating new or improving a sub-system for an existing device [UC2.2, UC2.4, UC7.1, UC7.2]
UC1.3. Identifying enabling technologies required (gap analysis) [UC1.1, UC1.2, UC2.4]
UC1.4. Generating ideas for optimising device: topology/scale(s)/location(s)/market(s) [UC3.1, UC3.2, UC2.4]
UC1.5. Assessing a current technology [UC2.1, UC7.1, UC7.2]

UC1.6. Identifying and quantifying challenges [UC2.3]
UC1.7. Identifying potential areas of opportunity [UC2.3]
Inputs: *User requirements (e.g. budget, risk, location, etc...) or technology characteristics relating to existing technology*
Output: *New concepts/ideas*

UC2. Technology Developers using Stage Gate design tools

UC2.1. Assesses what stage their technology is at including sub-systems and devices [UC1.5]
UC2.2. Comparison with standard benchmarks/ threshold (progression to next stage) (LCOE/other) [UC1.2, UC8.1]
UC2.3. Assessing areas of compliance & non-compliance [UC1.6, UC1.7, UC3.2]
UC2.4. Identify what needs to be done to meet the next stage [UC1.1, UC1.2, UC1.3, UC1.4, UC7.1, UC7.2, UC8.2, UC8.3]
UC2.5. Provide evidence for marketing/investment [UC3.3, UC7.1, UC8.4]
Inputs: *Technology characteristics*
Outputs: *Current stage; Steps to meet next stage; or an appropriate answer to the deployment and assessment design tools (energy yield etc.) depending on stage*

UC3. Technology Developers using Deployment and Assessment design tools

UC3.1. Assess how their device/technology works in an array cf. individual device [UC1.4, UC3.2, UC3.3]
UC3.2. Assess how their device/technology performs/behaves with different locations & balance of plant (either for single device or an array) [UC1.4, UC2.3, UC3.3, UC5.5, UC6.1]
UC3.3. Optimising the size of array and balance of plant for their specific device [UC2.5, UC3.1, UC3.2, UC6.2]
UC3.4. Provide evidence for marketing/investment [UC9.1]
Inputs: *Site and technology characteristics*
Outputs: *Outputs from deployment and assessment design tools (energy yield etc.)*

2.2.2 PROJECT DEVELOPERS

UC4. Project Developers using Structured Innovation design tools

UC4.1. Creating new or improving an array concept [UC5.3]
UC4.2. Identifying areas of opportunity, in terms of topology/scale(s)/ location(s)/market(s) for array/device/subsystem [UC5.3]
UC4.3. Identifying enabling technologies required (gap analysis) [UC5.3]
UC4.4. Identifying types of transition points in terms of array size/scale [UC5.2]
UC4.5. Assessing current arrays/technology [UC5.1]
UC4.6. Identifying and quantifying challenges
UC4.7. Identifying areas of opportunity
UC4.8. To get indications on where/how to focus use of the deployment design tools [UC6]
Inputs: *User requirements (e.g. budget, risk, location, etc...)*
Outputs: *New concepts/ideas*

UC5. Project Developers using Stage Gate design tools

UC5.1. Assesses what stage their project/array is at [UC4.5]
UC5.2. Identify when to upscale (transition points) [UC4.4]

UC5.3. Identify what needs to be done to meet the next stage [UC4.1, UC4.2, UC4.3, UC7.1, UC7.2, UC8.2]
UC5.4. Assess when to move between different stages of development (e.g. prelim. study > feasibility > detailed design) [UC8.3]
UC5.5. Assess enabling technologies and devices (acting like an investor based on outputs from SGM) [UC3.2, UC6.3]
UC5.6. Provide evidence for marketing/investment [UC8.4]
Inputs: *Technology and project characteristics*
Outputs: *Current stage; steps to meet next stage; or an appropriate answer to the assessment design tools depending on stage*

UC6. Project Developers using Deployment and Assessment design tools [UC4.8]
UC6.1. Assess how a device/technology performs/behaves with different locations & balance of plant (either for single device or an array) [UC3.2]
UC6.2. Optimise size/scale/balance of plant in the array [UC3.3]
UC6.3. Planning deployment and O&M [UC5.5]
UC6.4. Provide evidence for marketing/investment [UC9.1]
Inputs: *Site, technology & project characteristics*
Outputs: *Suitability of device for site; outputs from deployment design tools*

2.2.3 PUBLIC AND PRIVATE INVESTORS

UC7. Public and Private Investors using Structured Innovation design tools
UC7.1. Identify attractive areas of innovation for investment [UC1.1, UC1.2, UC1.5, UC2.4, UC2.5, UC5.3, UC8.3, UC9.3]
UC7.2. (Public) Design of funding calls [UC1.1, UC1.2, UC1.3, UC1.7, UC2.4, UC5.3, UC8.3]
Inputs: *User requirements (e.g. budget, risk, location, etc…)*
Outputs: *Ideas for investment/funding*

UC8. Public and Private Investors using Stage Gate design tools
UC8.1. Assess projects, devices, enabling technologies and (based on outputs from SGM) [UC2.2]
UC8.2. (Public) Assess if device/technology ready to go to the next stage? [UC2.4, UC5.3]
UC8.3. (Public) Identify R&D opportunities [UC2.4, UC5.4, UC7.1, UC7.2, UC9.3]
UC8.4. (Private) Assist in investment decisions [UC2.5, UC5.5, UC9.1, UC9.2]
Inputs: *Technology & project characteristics*
Outputs: *Outputs from assessment design tools*

UC9. Public and Private Investors Deployment and Assessment design tools
UC9.1. Assist in investment decisions [UC3.4, UC6.4, UC8.4]
UC9.2. Due diligence [UC8.4]
UC9.3. Future potential for array expansion [UC7.1, UC8.3]
Inputs: *Technology & project characteristics*
Outputs: *Outputs from assessment design tools*

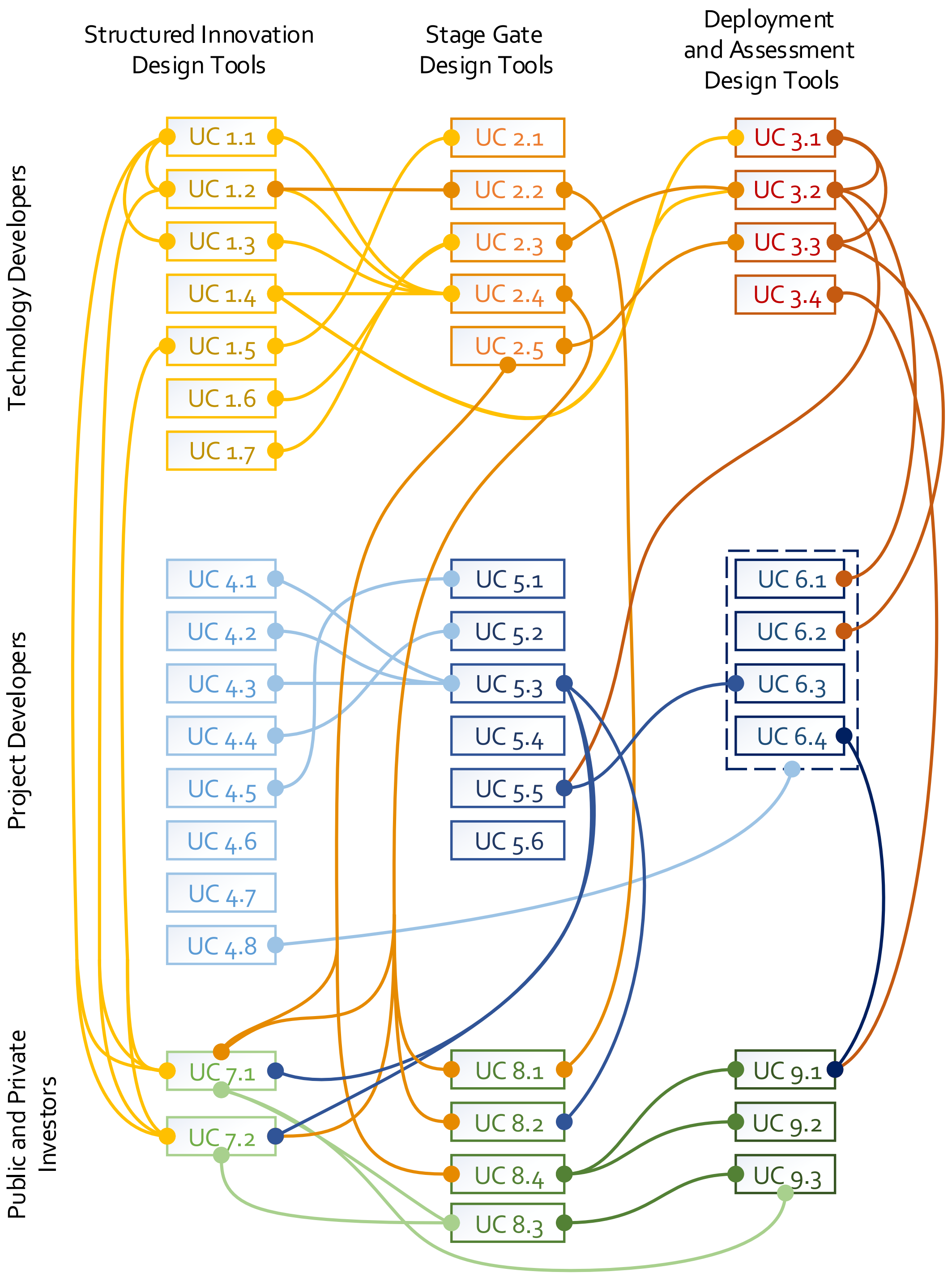

FIGURE 2.2 GRAPHICAL REPRESENTATION OF LINKAGES BETWEEN EXAMPLE USE CASES

2.3 GENERAL REQUIREMENTS FOR DTOCEANPLUS SOFTWARE

DTOceanPlus will support the design process for ocean energy technologies, both in the assessment and potential improvement of existing technologies and in the design of new sub-systems, devices, and arrays, to meet the requirements of a wide range of users.

The DTOceanPlus suite of tools should have a consistent and easy to use graphical user interface (GUI). In addition to the functionality required for each of the individual modules, the DTOceanPlus suite of tools will provide a method of visualising data and results. This will include both spatial data on maps/ charts, and numerical/statistical data in arrays, scatter plots, histograms, etc. This will be developed further in work package 7 Integration and Demonstration of Design Tools.

As with the original DTOcean software, DTOceanPlus will be made freely available as open-source software, for the benefit of the entire ocean energy sector. This will allow others to develop and build upon these tools, and will also allow them to be utilised for education, training and knowledge exchange.

Code verification and validation will be carried out in the DTOceanPlus project as the tools are developed and combined into the DTOceanPlus suite. The software will be developed with alpha and beta versions prior to the final release.

2.3.1 OCEAN ENERGY TECHNOLOGIES CONSIDERED

DTOceanPlus will be designed to consider ocean energy technologies to capture energy either from the waves or from tidal currents (also known as tidal stream), using devices known as Wave and Tidal Energy Converters (WEC/TEC). These technologies may be either moored floating devices, or fixed to the seabed/coastline. This gives four types of technologies that will be assessed by DTOceanPlus:

1. Fixed wave energy converter
2. Floating wave energy converter
3. Fixed tidal stream energy converter
4. Floating tidal stream energy converter

DTOceanPlus will not be designed to directly assess other ocean energy technologies, such as tidal range (impoundment via lagoons/barriers), offshore wind, ocean thermal energy conversion (OTEC), salinity gradients, etc.

To demonstrate the DTOceanPlus toolset, a series of test cases will be used to showcase the applicability of the tool to concept generation and selection, technology development, and farm deployment and optimisation. This will be completed for both wave and tidal energy scenarios, building on the work of projects such as EnFAIT (see section 1.3.1). The methodology for this will be defined in T2.3, with the assessment undertaken in T7.4 and T7.5.

Although there is significant commonality, specifically the goal of extracting energy from the harsh marine environment, there are also significant differences between wave and tidal energy devices. Some of the design tools will require separate functionality to assess Wave Energy Converters (WECs) and Tidal Energy Converters (TECs), with different code to assess these two different technologies. This will be addressed further as the technical requirements and tool specifications are further developed in subsequent tasks (T3.1, T4.1, T5.1, and T6.1).

2.3.2 ADDRESSING USER REQUIREMENTS

The user needs consultation, undertaken as part of task T2.1 and reported in deliverable D2.1 [6], highlighted a number of aspects that are expected of the DTOceanPlus suite of tools. Many of these considerations apply more generally to the whole suite of tools, and the key requirements are covered below. Points relating to specific design tools are covered in the relevant section(s) later.

- The need for a professional user-friendly product, which is easy to use and install, thus reducing requirements for training. This was a significant limitation identified for the original DTOcean software.
- Flexibility of the DTOceanPlus tools. This requires both an integrated suite of inter-compatible tools, but also the ability to use specific tools or modules independently.
- Compatibility with other software, both in terms of input/output and integrating DTOceanPlus with other tools, possibly by means of an application programming interface (API).
- Ability to deal with varying levels of detail and complexity. Fast computation at very early stages with more default input values, but also more detailed input at mid-to-late stage of the lifecycle of the project.
- Transparency of how the tools work, including documentation referenced to background research, and appropriate version control or parameter tracking.

Energy storage (such as batteries) is not part of the scope of the DTOceanPlus project, however this was requested as part of the user consultation. Storage is an important consideration for renewable energy projects, particularly considering short timescale fluctuations to address quality of supply. Therefore, it will be considered and included if possible.

2.3.3 KEY LIMITATIONS OR EXCLUSIONS

As with any software project, there will be limitations in the scope of the tools. It may not be possible to develop the functionality to assess particular aspects requested, or the data required to assess these may not be readily available. As DTOceanPlus will be open-source software, it may be possible for the sector to develop additional code later to address any limitations.

As with many other software tools, an unavoidable limitation of the DTOceanPlus tools will be that the accuracy of the outcome depends heavily on the input data. This is outside of the scope of the project to resolve, however the issue should be highlighted to users through an evaluation of a confidence level associated with input data, particularly when many default values are used and/or input data are sparse or low quality.

2.4 CORE TOOLS FOR DTOCEANPLUS TOOLS

A critically important aspect of the DTOceanPlus project is the integration of the suite of tools around a central core, provided by:

- A software platform with a Graphical User Interface (GUI)
- Digital models for the representation of ocean energy systems
- A global database

The selection of this core architecture builds on learning from DTOcean and expands of the benefits realised in that project. The following sections present the functional requirements for these core tools within the context of the DTOcean learning, user requirements from the users' needs consultation [6] and the resulting data requirements.

2.4.1 SOFTWARE PLATFORM

2.4.1.1 ADDRESSING USER REQUIREMENTS

The results from the user-groups consultation mainly show that users want to have an application which is simple to install and deploy. A major functionality which is also requested by the users is that DTOceanPlus should be able to exchange data from and to a wide range of formats. Other features asked were to have external Application Programming Interfaces (APIs) to interact with the applications, and to have a 'version control' mechanism to track changes on a model.

TABLE 2.4: FUNCTIONAL REQUIREMENTS FOR THE SOFTWARE PLATFORM

	Description
Operational requirements	Provide a platform on which the suite of DTOceanPlus tools can be developed and operated
Functional Requirements	1. Provide the ability to interface with users (e.g. a Graphical User Interface) 2. Provide import/export capabilities from/into several formats 3. Provide the ability to use tools/modules independently 4. Provide the ability to interface with external applications (External API) 5. Implement version control, if practicable

2.4.1.2 IMPLEMENTATION FOR DTOCEANPLUS

The DTOceanPlus application needs to have a modular architecture. Each tool will be implemented as an independent module. For example, the following modules can be created:

- Site Characterisation
- Energy Capture
- Energy Transformation
- Energy Delivery
- Station Keeping
- Logistics and Marine Operations

- Stage Gate design tool
- Etc.

It is also possible to create a "main" module that would be the entry point of the application, and where the user will define the project.

The main architecture should provide services to ensure a uniform User Interface (UI) across all modules (toolbars, menus, dialogs…), which will give consistency to the DTOceanPlus application.

Standalone usage

The DTOceanPlus' modules can be developed in a way that they can be run independently in a standalone mode, or with the rest of the modules in the DTOceanPlus application. This can be useful for users who want to use one of the tools, and who won't need to install the full platform but only one tool. A standalone module can work completely in independently with local data, but also use data from the database.

External API

Users want to have APIs (Application Programming Interface) to connect to the different applications and use them in "batch" mode. Each module will need to provide its specific API and generic services, such as the database access, will have one too. This API will also be used internally by modules.

Interaction between modules

Within the DTOceanPlus suite of design tools, modules will not interact directly with each other. The interaction between modules is done through the data. This can be through a main database or by exchanging files.

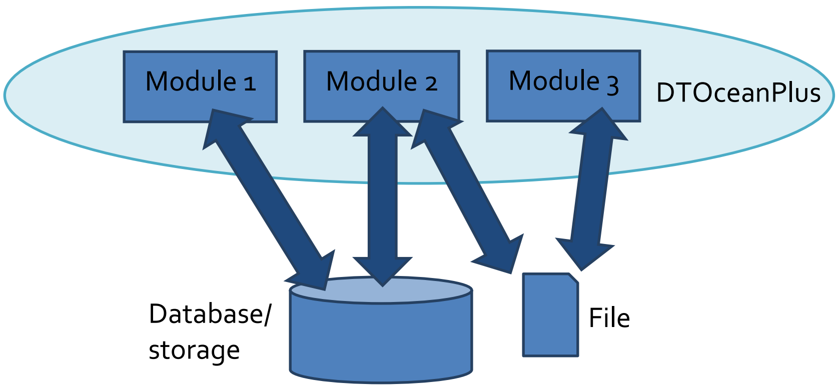

FIGURE 2.3: INTERACTION BETWEEN MODULES

Storage

The persistence of data can be ensured by using a classic relational database (e.g. PostgreSQL, Oracle), a document database (MongoDB), simple "file" database (SQLite), or using a standard file system structure with files and directories.

The reading and writing mechanisms will be implemented in the core layer of the application and be used by other modules.

Import/export

Import and export mechanisms will also be implemented in the core layer of the application. A generic import/export should be provided in a standard format such as CSV or XML (with a schema). External applications will be able to use this "pivot" format to convert data from and to their own format. Since the most requested format is Mathworks MATLAB, it may be possible to propose a specific solution for this. However, this depends on the type of data managed in MATLAB and required by each module.

Versioning

Since the DTOceanPlus application will be used to test viability of a project, the user should have the ability to test several options. For this a versioning mechanism should be implemented if practicable, so that the user can "fork" a project to test alternative options. This versioning mechanism should allow comparison of alternatives so that the user can choose to drop or retain an option.

2.4.2 DIGITAL MODELS FOR THE REPRESENTATION OF OCEAN ENERGY SYSTEMS

2.4.2.1 OUTLINE

The full suite of tools (Structured Innovation, Stage Gate, Deployment and Assessment design tools) in DTOceanPlus will rely on the **definition of digital models** to ease the representation of ocean energy systems. These models will account for the **different phases of the project lifecycle** (concept, feasibility or detailed design as defined in D2.1 [6]) and different aggregation levels, from components, to sub-systems to higher level systems. Work package 7 will create a digital representation of the information that runs in DTOceanPlus. Along with the creation of a structured definition of the system architecture, this will make it easier for the user to access and store **different levels of aggregation** and to **input an adequate amount of data** according to the stage of the project. This is confirmed by experience in other sectors, such as the Building Sector and by the trends and, more generally, the interests expressed by industry. Moreover, creation of a **standard format**, would make the **communication among different stakeholders** faster and will reduce the **software development** risks of inconsistency across different computational alternatives.

Table 2.5 presents a summary of the operational and functional requirements of the digital representation for ocean energy systems.

TABLE 2.5: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF THE DIGITAL MODELS FOR THE REPRESENTATION OF OCEAN ENERGY SYSTEMS.

	Description
Operational requirements	Provide a standardised digital representation of ocean energy systems, made of interrelated digital objects (digital twins)
Functional Requirements	1. Contain appropriate data to represent ocean energy technologies at different levels of aggregation (subsystem, device, array) 2. Contain appropriate data to represent ocean energy technologies at all the phases of the lifecycle of the project 3. Present digital twins which can be easily recognised by developers and users as standard definitions

2.4.2.2 DIGITAL MODELS IN DTOCEAN

The architecture of the original DTOcean was not developed with an underlying digital representation of the information. The data are organised – from a coding perspective – into about 40 Python-oriented data types, which helped the consistency of the information and the data flow among different computational packages. However, there was no correspondence between data and objects in the physical world, i.e. the step forward towards the digitalisation of the ocean energy sector was kept at an embryonic stage as the concept of digital twin was not tackled at that time. The development of digital models within DTOceanPlus is novel (and in general, a novelty for the ocean energy sector).

2.4.2.3 ADDRESSING USER REQUIREMENTS

Some useful information about the potential users of DTOceanPlus could be obtained by analysing the outcome of the user need consultation for DTOceanPlus [6]:

1. Popularity of the digital model representation in DTOceanPlus

During the user needs consultation, it was stated that information will be collected and structured through a digital model representation. Most of the respondents (88% [6]) indicated they would use the DTOceanPlus toolset at some point in the project lifecycle, and so would implicitly interact with such digital models.

2. Speed, usability and easy access are the most demanded features.

The use of digital models will speed up the process of formatting/inputting information and taking "snapshots" of the outputs at different aggregation levels: this is something seen as beneficial by most of the users, with speed and usability being the most demanded features (see Figure 3.5, Figure 3.7 and Table 3.2 of [6]).

3. The definition of digital models is useful.

It is inferred from Figure 3.14 [6], that the possibility of using a standardised approach for digital representation is seen by the participants of the survey as useful for at least three reasons: a) to deal with different stages in the development process; b) to handle data with different levels of complexity as the project develops; c) to investigate different technologies in a unique manner.

4. **The digital representation will improve the current lack of consistency among different tools**
   As shown in the Section 3.7 of [6], the users have expressed concern that data flows can become inconsistent, creating difficulty when managing interaction of different tools. The digital representation would smooth the interfaces with other tools by using a consistent data format.

Therefore, the digital representation is beneficial throughout the lifecycle of the project, from concept through feasibility and detailed design. In DTOceanPlus, Task 7.1 (Digital representation of ocean energy systems) will aim to achieve a full representation of the physical system through the definition of "*digital twins*", enabling the capture of different characteristics of the system at different levels of aggregation (array – devices – sub-systems – components). This "digitalisation" process will enable the implementation of consistent data flows among the different tools, as well as accelerating the standardisation of the required information, depending on the development stage (TRL) of the technologies.

It is challenging to create a digital model architecture to account for different levels of granularity/coarseness of the data, according the stage of the project. To have them all aligned, this task should be carried out together with the development of all the other tools and the global database.

The digital model representation for ocean energy systems should be able to capture all the different levels of aggregation: **sub-systems, devices and arrays**. Attention should be paid, however, to the potential interconnections among objects/digital twins at the same level from the same branch or even at different levels but belonging to different branches. These are situations that must be tackled to avoid any inconsistency.

Another benefit of the digital representation is that users will have a clear idea of what information would physically represent each object, conceptually making it easier to input data to the toolset. However, the project must consider from a practical perspective how the digital object will be used to manage input and output of this information. One possible approach would be to allow the user to do this through the Graphical User Interface (GUI) with the ability to select the format of the file (input/output) making the process easy and fast.

2.4.3 GLOBAL DATABASE

2.4.3.1 OUTLINE

All the DTOceanPlus tools will require a large amount of data to perform the computations they are designed for. Conveniently, as it was in the DTOcean platform, data will be stored in a **global database**, whose main functionality is therefore to store input data. The purpose of the global database is: (a) to *reduce the burden on the user in the phase of inputting information* before running the tools as well as (b) to *provide a static source of stored data* which could be used not only while running several simulations using the same scenario/project, but also for different scenarios/projects.

In Table 2.6, there is a summary of the operational and functional requirements of the digital representation for ocean energy systems.

TABLE 2.6: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF THE GLOBAL DATABASE

	Description
Operational requirements	Reduce the burden on the user in the phase of inputting information and provide a static source of stored data to support the DTOceanPlus suite of tools
Functional Requirements	1. Store appropriate data to support the functions of the standardised digital representation at different levels of aggregation (subsystem, device, array) 2. Store appropriate data to support the functions of the standardised digital representation at all the phases of the project lifecycle 3. Interface with the user to allow input and output of data, possibly through the Graphical User Interface 4. Interface with the full suite of DTOceanPlus tools to allow input and output of data 5. Implement validation procedures that guarantee levels of confidentiality.

2.4.3.2 THE GLOBAL DATABASE IN DTOCEAN

In DTOcean, the global database was designed to interact with the "Core", i.e. the main interface between the computational modules, thematic algorithms and the database [7]. Figure 2.4 shows the role of the database within the framework of the full set of DTOcean Tools.

The database contained long-standing reference data and data relating to particular array design projects. To this purpose, as it could be seen in Figure 2.4, despite being a unique entity, the database was virtually portioned in two parts, containing (1) **Reference database** and (2) **Project database**.

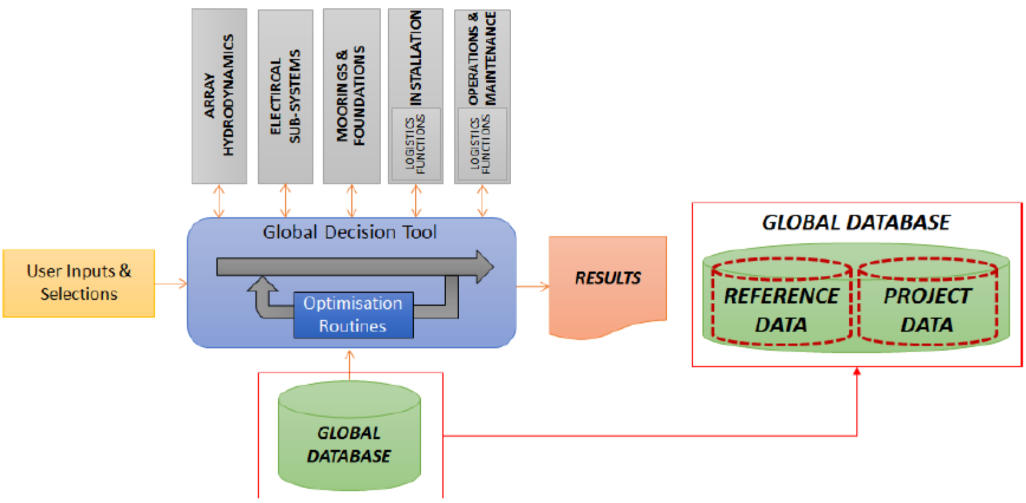

FIGURE 2.4: THE ROLE OF THE GLOBAL DATABASE IN DTOCEAN AND ITS VIRTUAL PARTITIONING [7]

The reference database fulfils both the purposes (a) and (b), i.e. it is essentially a data catalogue containing static data, including information about electrical components, mooring/foundations components, vessels and ports. All this information, indeed, can be shared whatever the project is, either tidal or wave. On the contrary, the project database contains information that should be entered by the user for a specific project in order to run one or more simulations. Moreover, as the project database may contain sensitive data, functionalities to trace data and deal with confidentiality issues may be required. Such a pre-process would be a one-time process; once included in the project database, the data could be used as many times as desired without need of re-entering. The data contained will relate to the location as well as on the technology, i.e. device-specific data as well as bathymetry of the site, metocean characteristics, geotechnical description of the soils and a number of physical characteristics unique to the site of interest.

The database in DTOcean was built as a relational SQL database. One of the functions which has not been covered in the DTOcean database was the possibility of storing the data for intermediate solutions, while calculating the final results or the final results themselves. This means that the database, which is fully consultable, interacts with the tools unilaterally, providing data to the "Core", but not on the other way around.

2.4.3.3 ADDRESSING USER REQUIREMENTS

Despite there being no dedicated section/questions about the database in the user needs consultation for DTOceanPlus [6], some conclusions can be drawn about the user needs based on their answers in terms of general functionality of the tools.

1. Popularity of the database feature in DTOcean/DTOceanPlus
First of all, 25% of the participants (see Figure 3.4 of [6]) actually used the previous toolset DTOcean, so they are aware that a database was included. Nevertheless, it seems that users are not aware of the current functionalities of the database in DTOcean, as they desire the functionality of "importing data from a wide range of sources to be used in DTOceanPlus", "incorporating results from other software tools into the global database, so that these can be used within DTOceanPlus", and "saving the input parameters and/or model output to a file". Since some of these functions were actually possible in the original DTOcean, it is clear that there needs to be information provided on how to manage the database.

2. Speed, usability and easy access are the most demanded features.
The potential users require accuracy and speed as part of the requirements (see Figure 3.5 of [6]). Similarly, for the database, information should be sufficient and adequate to the stage of development of the technology/design and to the availability of data. The potential users have identified the requirement of quick computations at concept stage, while allowing more time when using DTOceanPlus at the design stage where there is likely to be access to more data. The majority of funders & investors, as well as policy & regulators are more likely to use the tool at the earliest, higher level conceptual stage. This means that the project database (and requirements in terms of data) are likely to not be very detailed at this stage. Also, the time spent for the data inputting is crucial for the users (see Figure 3.7 and Table 3.2 of [6]): they expect such an operation to be fairly quick at

conceptual stages. This confirms that the implementation of a project database in DTOcean was beneficial to ensure that data could be pre-processed in advance using easy SQL scripts. However, even if in DTOcean it was possible to overwrite data through the graphic user interface GUI, it was not possible to populate database through the GUI; probably adding an extra functionality of loading new entries in the database through the GUI would be highly appreciated as it would speed the process a lot, or at least it could make it easier and more visual. Usability and ease of use and update of the database is what is expected by the potential users (see Figure 3.13 of [6]). Modularity, and keeping the Database as separate from the rest of the tools, are characteristics the user appreciated.

3. Improvements of the DTOceanPlus database with respect the DTOcean database

In general, it seems that most of the choices taken in DTOcean reflect the user needs; so it is expected that only a gentle restructuring is required, in order to be consistent with the digital representation of the objects included into DTOceanPlus, and add some extra functionalities to make the access to the database easier through the GUI.

The global database, therefore, **should be able to store data with a level of detail corresponding to the level of complexity required by the stage of the lifecycle of the project.** As identified during the user needs consultation, the concept stage must be characterised by high-speed and coarseness of data; moreover, the concept and the feasibility stages are those levels that the user mostly will use DTOceanPlus; for this reason, it appears reasonable that the information stored in the database should have a level adequate for these stages; extra information may be included, but without losing sight of what users consider important: speed in accessing and inputting the data.

More advanced validation procedures (logical advanced validation (check and rule)) of the data may be introduced to help management data, extending those already available in DTOcean (data type, field size, nullability and uniqueness). Data could be characterised by extra fields to identify the level of uncertainty of the data.

Both the reference and the project **database** (the global database) **will contain data**, as per the DTOcean database, at any level: **sub-systems, device and arrays**. Most component data are included in the reference database, while device specific information and array data are generally contained in the project database, as they refer mostly to a specific project and they could not be part of a catalogue.

The characteristic of the DTOcean database to be accessed externally though any SQL based software is important, as identified by the users; this should be reflected also in the DTOceanPlus database. The user should be able to access, add and edit entries as well as modify them either from the tool (through the GUI) or externally. This is a feature that seems that should be preserved and if possible expanded, especially the internal interaction with the GUI.

Similarly, it seems that some of the limitations of the current DTOcean database will apply to the DTOceanPlus database; for example, it is consistent with the outcome of the user need consultation that no intermediate results should be stored in the global (external database) as this would slow down the process notably; these results will be stored in the digital twins as attributes.

3. STRUCTURED INNOVATION DESIGN TOOLS

3.1 INTRODUCTION AND CURRENT STATE-OF-THE-ART

Structured innovation approach refers to the systematic process of innovating, identifying, developing and validating novel technology. As a set of modules, the Structured Innovation design tools facilitate the implementation of the stakeholder's requirements followed by the selection of achievable innovative options. Inputs from marketing, engineering, intellectual property management and policymakers are valuable to the innovation process.

DTOceanPlus will introduce new design tools to integrate Structured Innovation within the process of ocean energy design. Three modules will be built, each implementing a key methodology:

1. Quality Function Deployment (QFD),
2. TRIZ (Theory of Inventive Problem Solving), and
3. Failure Modes and Effects Analysis (FMEA).

The origin of the individual modules (QFD, TRIZ and FMEA) and their successful applications worldwide are already more than three decades old, used to develop new concepts, products or services.

Current state-of-the-art

Most companies developing new products or services use a form of the structured innovation process to identify, create, and develop innovative solutions, measure 'success' against their competitors, and manage the uncertainties and risks associated with the implementation processes. This is seen across a wide variety of sectors in companies such as ExxonMobil, Ford Automotive, Rolls-Royce; companies in the medical and pharmaceutical industry, and many more.

The Ford Motor Company used a structured innovation approach to facilitate new technology introduction for the development of low-cost independent rear-suspension, known as "Control-Blade" and was first used on the original Ford Focus. The initiation was from a corporate strategic decision to consult customers, and this gave a requirement for improved ride quality, but with contradictions of improved cornering, and lower cost. The approach taken developed an intimate understanding of the customer's requirements, with emphasis on the contradictions and their relative impacts. The results of this showed that these contradictions needed to be solved by radical innovation rather than incremental improvements since the existing technologies could not solve all requirements. TRIZ was used to solve these contradictions, using three of the 40 inventive principles to bring a cost-reduced independent rear suspension to medium-size cars that had only been possible in premium cars. The innovations were the modularity, energy conversion, and light-weighting [33]. The company uses the combined QFD and FMEA approach which is fully integrated in some of its tools: EQUIP (Engineering Quality Improvement Programme) and FTEP (training & technical quality skills), the Ford Motor ULEV (ultra-low emission vehicles), the Exhaust gas ignition (EGI) system, Electrically Heated catalyst (EHC) system, etc. [33].

Toyota integrated the QFD analysis in the company's areas of product design to meet the user's needs. According to Sullivan [34], the company reported a 61% reduction in start-up costs, a one-third reduction of the product development cycle (time to market), and fewer design changes overall. A case study at Eaton Corporation found that the use of QFD to design blend door actuators for automobiles resulted in: 30% reduction in size, 50% reduction in selling price, 50% reduction in engineering expenses, 20% reduction in drafting expenses, a reduction in noise from 50 decibels to 38 decibels, and mounting flexibility allowing it to be used on three additional car lines [35].

Rolls-Royce introduced a Requirements Capture and Management (RC&M) and Systems Engineering (SE) initiative to improve its design processes, in particular: the lead times, the costs of rework because of poor translation of customer requirements to result in the improved robustness of their solutions. The company adopted the DOORS (Dynamic Object-Oriented Requirements System) software as an Enhanced Customer Integration tool. Like the QFD, this tool captures all individual requirements and integrates them in the processes throughout the product life. One example was the use of the QFD tool in the Rolls-Royce Power Engine Plant programme to understand and structure their new engine. The customer needs were addressed and translated into "functionality" for the engine's functional requirements from the system to further down into key subsystem requirements. QFD combined with Pugh Matrices assessed the various options against the user requirements before settling on a design solution and moving to the characterisation phase to build a robust design process [36]. With the need to increase automation at the early stages of the process to increase performance attributes such as weight, fuel consumption, cost, noise and turbine entry temperature, Rolls-Royce relies on modelling tools such as QFD and TRIZ to capture their customers' needs and ensure the trade-offs between attributes are resolved without increasing complexity to the design. [37]

The combination of QFD, FMEA and the 40 inventive principles was applied by Converteam (now GE) during the development of a novel electric drive system. The drive system would compete against established solutions and would need to be able to provide compelling reasons for use and clear commercial benefits. GE is an enthusiastic user of six-sigma/lean-engineering-based tools and decided to use QFD to represent the voice of the customer through the technology decision process. Their approach to QFD was characterised using intense customer engagement to derive the needs and their relative importance by using a paired question analysis. This analysis showed that using a robust technology used in the mining industry would provide differentiation and significant cost benefits. The integration of their QFD and cost analysis was impactful in the extremely competitive cost per unit thrust that their innovation achieved. The DTOceanPlus Project will aim to use part of their approach to ensure creative inventions that have market acceptance and low cost and risk profiles.

Siemens Wind Power has used a combination of QFD, TRIZ and FMEA to select technologies and overcome technical and commercial challenges associated with the development of wind turbines suitable for offshore applications, and some of the key components required. In this case, the use of integrated TRIZ, FMEA and their toll-gate processes meant that a highly innovative solution was found that allowed them to tackle both design and manufacturing/supply chain issues that could have prevented the rapid time-to-market and preparedness that is essential to building a new business solution in a growing market. The application of at least six of the 40 TRIZ inventive principles is apparent, as evidenced by the highly modular design, with a combination of functions included in each module.

In the ocean energy sector, the adoption of structured innovation methodologies is less evident. The US-based National Renewable Energy Laboratory (NREL) and Sandia National Laboratories use a structured innovation approach to identify and develop new wave energy converter concepts with high techno-economic performance potentials [38]. Project SEAWEED by Wave Energy Scotland is developing a structured innovation tool to "identify attractive scenarios for exploitation of wave energy resources". As a standalone package, the SEAWEED module facilitates the creation of concepts by scanning the design space and the selecting the most attractive and achievable options. The evaluation could be based on high-level metrics such as Internal Rate of Return of an Investment, Payback Time, Commercial Risk, and Technical Risk [39].

Various sectors have adopted structured innovation methodologies to innovate their products and services. It is worth noting that the adoption of these methodologies is more advanced and matured in some sectors (e.g. automotive) more than others (wave or tidal), however, their approaches implement only parts of what is needed to innovate systems in a structured manner.

As far as the authors are aware, the Structured Innovation design tools within the DTOceanPlus suite is one of a kind beyond the current state of the art, that enables the transfer and adaptation of the QFD, TRIZ and FMEA modules to the ocean energy sector. Hence for a sector such as ocean energy where the number of design options is still very high, the proposed open-source Structured Innovation design tools are needed to help deal with the complexity of the engineering challenge – resulting in a more efficient evolution from concept to commercialisation.

Although the Structured Innovation tools used in other sectors can be considered to be at TRL 9, in transferring and adapting them to the ocean energy sector a reduction in TRL to 4 is appropriate. Therefore, in addition to bringing Structured Innovation tools into the sector, DTOceanPlus will develop these tools from TRL 4 to TRL 6, firstly validating them against relevant scenarios, then demonstrating them in real-world use.

3.2 REQUIREMENTS FOR STRUCTURED INNOVATION IN DTOCEANPLUS

3.2.1 OUTLINE OF THE STRUCTURED INNOVATION DESIGN TOOL REQUIREMENTS

Structured development refers to the systematic process of innovating, identifying, developing and validating novel technology. The DTOceanPlus tool will create and demonstrate advanced design tools to encourage solutions to the challenges found with the first ocean energy sub-systems, devices and arrays.

As part of DTOceanPlus, the Structured Innovation design tools are used in the formative, conceptual phase for concept creating, selection and design of ocean energy technologies. The Structured Innovation methodology is required to broaden the design focus; to scan the totality of the design space and to identify and create promising concepts, ensuring every potential winner is assessed and has objective scrutiny. The methodology is also used in later phases of product development to help address emergent challenges, and sometimes to reappraise and redesign components or systems to overcome such challenges. This methodology can therefore be used at all stages, and at several levels from system level down to component level.

Work Package proposed the use of the Quality Function Deployment (QFD), TRIZ (Theory of Inventive Problem Solving), and Failure Modes and Effects Analysis (FMEA) to provide a marine-energy enabled set of tools for a structured innovation framework.

As input to the Structured Innovation design tool, the findings from the user-needs consultation published in Deliverable 2.1 [6] are analysed to capture the stakeholders' requirements. These requirements enable identification, development and validation of the SI design tools.

This will be achieved through the functions presented in Table 3.1:

TABLE 3.1: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF THE STRUCTURED INNOVATION DESIGN TOOL

	Description
Operational Requirements	Facilitate application of systematic processes for the innovation, identification, development and validation of novel ocean energy technology
Functional Requirements	1. Scan the design space and identify attractive areas of innovation 2. Create new concepts and identify areas of opportunity 3. Identify and solve the contradictions arising from the proposed solutions 4. Mitigate the potential technical risks associated with the attractive concepts to satisfy the user requirements

3.2.2 DETAIL OF FUNCTIONAL REQUIREMENTS

1. To scan the design space and identify attractive areas of innovation

The Quality Function Deployment (QFD) will be used to firstly scan the design space by mapping options of key parameters which make up ocean energy concepts or projects, then ranking the attractiveness of these scenarios through high level physical and economic assessments. Secondly, QFD will be used to define the innovation problem space to represent the voice of the customer and make immediate objective assessment of the best solutions which fit the users' requirements. The standard QFD technique used in the automotive industry will be developed further and adapted to include fundamental relationships between key parameters in ocean energy concepts, evidence from the first ocean energy arrays, and a standard library of problem solution inter-relationships. QFD uses a set of requirements (the "whats") and answers them with a set of solutions (the "hows"). There will be a variety of solutions to solve each requirement, with each solution being aimed at producing the best requirement improvement. These solutions may contradict each other, and the QFD method allows these contradictions to be identified, and their impact assessed.

2. To create new concepts and identify areas of opportunity

The creation of all possible concepts will be ranked in order of importance and achievability highlighting scenarios which would be attractive investment opportunities. Evaluation of these scenarios will be based on high-level metrics such as Internal Rate of Return (IRR) of investment, Payback time, profit per kWh equivalent, Cost of Energy, etc.

3. To identify and solve the contradictions arising from the proposed solutions

TRIZ is a systematic inventive problem-solving method that will be used to produce solutions to the QFD requirements where an improvement is needed, or if there is no existing solution, or if the key performance indicators are not satisfactorily met. The TRIZ method can be used to ensure completeness in the key parameters which define the design space with, for example, use of the Effects Database and in the series of provocative prompts to provide the well-known forty inventive principles and other tools to solve contradictions contained within the QFD. These two methods will be linked within the set of tools to allow visualisation of areas of opportunity and risk.

4. To mitigate the potential technical risks associated with the attractive concepts to satisfy the user requirements

Technical risks will be framed by using the concept or design FMEA tool, linked to QFD. The FMEA will provide ratings for each defect or failure in terms of severity, occurrence and detection. The FMEA will use a database of validated defect parameters to improve understanding of technical risk during the design assessment process, but also to offer opportunities for both risk mitigation and cost-reduction.

In the tools, the structured innovation process will conclude with a visualisation method to represent the process and results obtained, and deviation from the key performance metrics. The results will be expressed in terms of a ranking of attractive scenarios and in presentation of the QFD requirements (for example, could be cost of energy and reliability, amongst many). The overall result will be an acceptability rating that allows objective assessment of the design.

3.2.3 FUNCTIONALITY IN PRACTICE

The Structured Innovation design tool will identify attractive areas of innovation for investment and facilitate the implementation of the stakeholder's requirements to enable the generation of achievable innovative design solutions. These will use valuable inputs from marketing, engineering, Intellectual Property management, policy makers and the user needs' consultation [6].

The origin of these individual modules (QFD, TRIZ and FMEA) and their successful applications worldwide are more than 30 years old and have been used as standalone tools, or combined QFD/TRIZ, QFD/FMEA as well as in combination with other quality management tools [40]. The further development under the DTOceanPlus project will simplify their application, replace some of the subjective input with objective measures, provide validated inputs, and make the process faster.

Examples of how the Structured Innovation design tools could be used in practice is outlined below for the use cases defined in section 2.2. Other examples are also given above under state-of-the-art.

As observed from the User Needs Consultation responses [6], the Structured Innovation design tools are a very impactful set of tools, mainly to assess the development stages of the devices (total of Important/very important results: 42%—Devices, 30%—Sub systems, 28%—Arrays assessment).

Use Case 1: technology developers

The technology developers may use the Structured Innovation design tools to facilitate concept creation of new or improve device or sub-system designs by scanning the design space and mapping the options of all scenarios. These will be integrated with the user requirements to produce product specifications by identifying the potential design solutions for research and development. The combined QFD/TRIZ/FMEA modules will ensure the proposed solutions best suit the user requirements.

An example of that would be a wave technology developer investigating the potential of developing an oscillating wave surge converter nearshore; to understand the optimum physical attributes of the environment and the structural limits of such devices. The Structured Innovation design tools will assist in identifying the design challenges. It would then be linked to the QFD/TRIZ/FMEA modules to filter the results to those solutions which best suit the user requirements. Potential concepts and designs with achievable targets would be proposed, such as potential sites, materials used, or device geometry.

Use Case 2: project developers

The Project developers may use this tool to select back the technologies or device concepts with the most commercial potential, focussing on the commercial deployment of the devices (single units) or arrays (mass production).

Project developers could be interested in using the tools at conceptual or improvement stage of the project. The SI design tools can be used to mitigate potential risks of a particular design choice, for example updating the induction generators to permanent magnet direct drive machines for all the turbines in the array. The QFD/TRIZ/FMEA modules will evaluate the impacts of implementing the proposed concepts with respect to reliability, overall costs and payback returns.

Use Case 3: public and private investors

Public and private investors will use the SI design tools to identify attractive areas for R&D investment. By scanning the design space and using the QFD/TRIZ/FMEA processes, promising concepts and areas of innovation will be highlighted. This will facilitate the guidance of future support mechanisms to ensure the best technologies are funded.

3.2.3.1 OUTPUTS

The outputs of the Structured Innovation design tools will be:

- Attractive scenarios for investment in ocean energy technologies
- Recommended stakeholder- driven design concepts (future direction of development)
- Essential technical specifications for the proposed solutions
- Potential technical & commercial risks associated with the proposed design concepts

3.2.4 ADDRESSING USER REQUIREMENTS

The stakeholders' requirements were captured from the users' needs consultation [6], highlighting some of the requirements for the Structured Innovation design tools (more details in TN2.2 [5]):

- Ability to assess innovation potentials against the technical risks of concepts to design
- Ability to quantify the challenges
- Generate optimum solutions for devices and arrays
- Identify the potential R&D opportunities and Investments
- Enable the development of funding calls to support identified attractive technologies
  - In-built provision of clear constraints/targets and benchmarks
  - For due-diligence in ranking enabling technologies
- Conformity with existing rules and standards
- Provide commercial innovation opportunities (IP generation)
- Comparative assessment tool
- Reliable & Repeatable tools
- Pathway for investors
- Technology Development pathway

3.2.5 APPLICATION OF STRUCTURED INNOVATION DESIGN TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

3.2.5.1 USE THROUGHOUT THE PROJECT/TECHNOLOGY DEVELOPMENT

The Structured Innovation design tools can be used at all stages of development from the early stages of innovation to late stage of deployment to generate new concepts; including novel concepts for wave and tidal energy devices, or improvements of a sub-system, device or array. The Structured Innovation design tool also provides the ability to assess technologies at the early concept stages when there is minimal data available and will inform part of the inputs for the Stage Gate design tool.

TABLE 3.2: ASSESSMENT METHODS AT EARLY, MID AND LATE STAGE IN PROJECT LIFECYCLE

Early	Mid	Late
▫ Qualitative assessment ▫ User requirements	▫ Risk Assessment ▫ Concept creation and selection	▫ Testing and Verification ▫ Improvements of concepts
▫ High subjectivity ▫ High Risks ▫ High Uncertainties	▫ More Objectivity ▫ Accessed Risks ▫ Align with standards	▫ Reliable and Repeatable assessment ▫ Quantitative assessment
▫ Default Input (stored database)	▫ Customised Input (combination of existing dataset and user's data)	▫ Complete data input and analysis

Early stage: At the early stages of development, the Structured Innovation design tools are likely to be used for the simplest qualitative assessments to scan the design space and identify the potential design concepts in ocean energy systems including sub-systems, devices and/or arrays. Some scoring criteria can be used at this stage to prioritise the user's needs and define the technical requirements to meet those needs. For example, if a user wants to build an affordable wave device, this might be achieved by minimising the capital expenditure costs, maximising the energy yield and improving the maintenance strategies.

Mid Stage: From concept creation, the feasibility of the concepts may be analysed, moving from a qualitative assessment with little data to a more quantitative assessment with increased objectivity. At this stage, the user might be able to use less default values and input bespoke parameter values. This stage is more accurate than the early stage with additional data requirements.

Late Stage: This stage is more detailed than the early and mid-stages, with more parameter values available from testing and/or numerical modelling. Fully defined input parameters are likely to be available at this stage, enabling complete quantitative assessment and sensitivity analysis to reduce the uncertainties and initial assumptions.

3.2.5.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

Users of the Structured Innovation design tool will be able to create and select promising concepts in ocean energy systems by addressing the engineering complexity of the system from the concept to commercialisation stages.

The tool includes the development of functional relationships to drive very early stage assessment and concept creation work. It is intended that the user of these tools will input the available data related to their concept/design at the beginning of the use of the Structured Innovation design tools. This will in turn generate default values for the type of technology, topology, location and characteristics. Criteria metrics will be filtered accordingly, and the default values will be generated to create the possible design concepts and characterisations.

The Structured Innovation design tool will work alongside the Stage Gate design tool to assess the fundamental engineering parameters of the proposed concepts against the topic areas in the stage gate metrics framework. The Structured Innovation design tool also require computation of parameters by the relevant Deployment and Assessment design tools to inform the engineering, physics and economic fundamental relationships and provide tools to support evaluation of requirements and solutions in the QFD.

Depending on the technology's level of maturity, the users can acquire default data from the appropriate database (e.g. hydrodynamics, met-ocean data, or transmission) stored in the Digital Representation to enable the identification of enabling technologies. However, as concepts mature, more customised data can be input, increasing the certainty levels. The removal of subjectivity by increasing the use of data-driven assessment in the Structured Innovation design tool will decrease the level of uncertainty and add credibility to the tool.

3.2.5.3 SUB-SYSTEMS, DEVICES AND ARRAYS

The Structured Innovation design tool will generate new concepts for sub-systems, devices and arrays. This may be an improvement to an existing ocean energy system, or the generation of a novel concept which provides an attractive solution to the users' requirements.

3.2.6 INTERFACES

3.2.6.1 GENERAL TYPES OF DATA TO BE CONSIDERED

The types of data will vary with the availability of data which will depend on the stage(s) in the project lifecycle as described in Section 2.1.2. At the early stages of technology development, there will be inputs from marketing, engineering, service, IP management and policy makers into the Structured Innovation design tools, including the common metrics developed in work package 4, contributing to the high-level targets that represent successful implementation. Best-practise methods from Aerospace and Automotive sectors will be selected and adapted for DTOceanPlus suite.

3.2.6.2 REQUIREMENTS FROM OTHER DTOCEANPLUS TOOLS

Here, we define the requirements that the Structured Innovation tools will have from other tools within DTOceanPlus suite. Figure 3.1 illustrates links and relations between the Structured Innovation (SI), Stage Gate (SG) design tools, see also TN2.2 [5].

Deployment and Assessment tools

The Structured Innovation design tools will require high level assessments including lifetime costs and reliability to measure the attractiveness of concepts which are generated, which will be outputs of the Deployment and Assessment design tools. A high-level summary of the requirements for the Deployment and Assessment tools are that they will:

1. Inform the engineering, physics and economic fundamental relationships which drive the earliest stages of assessing the attractiveness of concepts
2. Provide simple tools to support evaluation of requirements and solutions in QFD at early stage – i.e. objective QFD scoring. These may be the full complexity tools with default inputs.
3. Link to complex tools applied through Stage Gate design tools to guide improvement needs in later stage technologies and prompt use of Structured Innovation design tool.

Stage Gate design tool

The Structured Innovation design tool will require the same assessment processes as the earliest stage assessments (lowest TRL technologies) of the Stage Gate design tool. The Structured Innovation and the Stage Gate design tools are strongly linked in their functionality.

- New concepts which are created as part of the Structured Innovation design tool will be fed into the Stage Gate design tool and they will utilise the simplest versions of the assessment and deployment tools to assess these concepts. These may be based on fundamental engineering, physics and economics relationships, or stripped-down versions of the assessment tools with default values for many of the variables.

- Throughout technology development, technologies may be output from the Stage Gate design tool with highlighted areas of improvement and technical challenges which can be fed into the SI design tools to be reappraised and sub-systems or the system redesigned to overcome such challenges with the suggestion of concepts, guidance for concept creation or highlighting areas of promising scenarios.

3.2.6.3 EXTERNAL INTERFACES

The Structured Innovation design tool will be compatible with some of the following tools to enable pre- and post-processing of data to/from other software: including Microsoft Excel, CSV, some quality management specific tools such as DfSS (Design For Six Sigma), DOORS (Dynamic Object-Oriented Requirements Systems), and other Lean ISO Quality Management Systems tools; most risk mitigation tools such as FTA (Fault Tree Analysis), PRA (Probability Risk Assessment), FMECA and complementary TRIZ tools such as Axiomatic design tools, etc.

In addition, one of the respondents expressed the need to have a multi-user interface offering the capability for various users to input data and perform various analysis in the different modules of the tools: "*It is essential to have a tool that can be used by multiple users and that can be connected to other modules than those developed in DTOceanPlus (but which would have the same purpose).*"

3.2.7 KEY LIMITATIONS OR EXCLUSIONS

- High level of subjectivity of the SI design tools in the Alpha version. The initial digital version of the tool (the alpha version) will use individual/panel scoring which is a subjective assessment, this will be reduced as the tool automated to add clear scoring criteria to assist the assessors and have an in-built score calculated by the DTOcean Assessment and Deployment design tools.
- Expert assessors: the ability to gather a wide range of stakeholders to evaluate the importance of each process/component and establish the What-How relationship in the HoQ matrix.

3.2.8 SUMMARY

The Structured Innovation design tool will be used to assist the stakeholders in creating and generating new concepts of innovations for investment. In combination with other DTOceanPlus tools, the Structured Innovation design tool can be used at all the stages of the project lifecycle to assess potential concepts at low to high TRL levels for devices, sub-systems and arrays. The ability to self-learn to use the tool, to spend as little time as possible inputting the data in the Structured Innovation design tool and the flexibility to import or export data to other software are some of the requirements from the stakeholders.

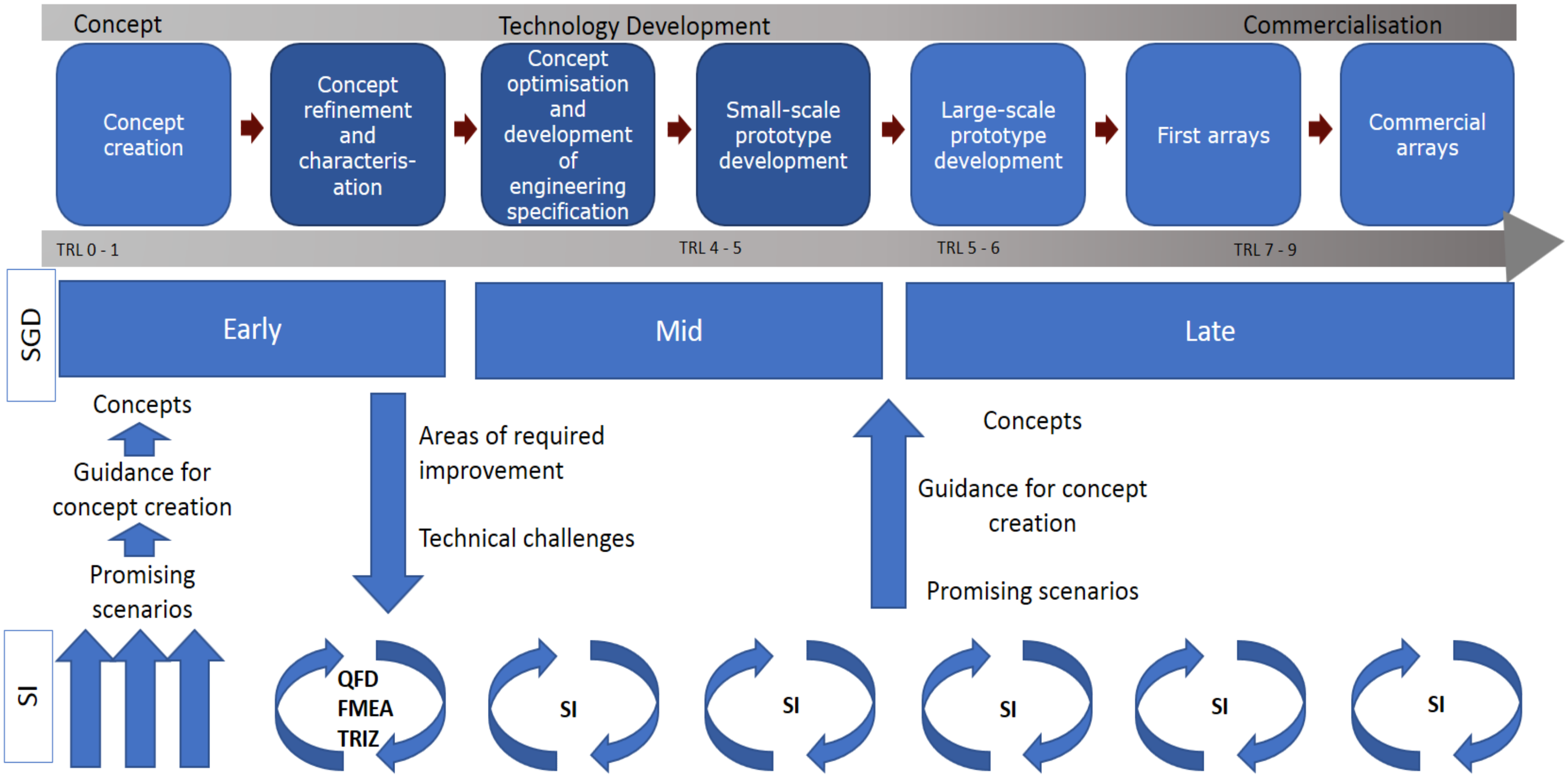

FIGURE 3.1: REQUIREMENTS OF THE STRUCTURED INNOVATION DESIGN TOOLS FROM/FOR OTHER TOOLS IN THE DTOCEANPLUS SUITE

4. STAGE-GATE DESIGN TOOLS

4.1 INTRODUCTION AND CURRENT STATE-OF-THE-ART

The Stage Gate design tool is a completely new feature of DTOceanPlus, bringing structure to the technology development process by using the stage gate process as the basis of its functionality. The aim of this tool is to guide the technology development process, give users an understanding of what stage of development technology is at within a stage gate framework and facilitate the assessment of ocean energy technologies. This tool will guide the user in the assessment of a sub-system, device or array to support technology development from concept to commercial deployment. As a tool, it will function with close integration to the Structured Innovation, Deployment and Assessment design tools to support consistent assessment processes and ultimately guide decision making for the users of the tool.

Stage Gate design tool state-of-the-art

Most companies developing new products use a formal development strategy, and having an effective stage gate process has been proven to drive innovation [41] [42]. This is seen across a wide variety of sectors in companies such as Exxon, Visa, Microsoft and Guinness who use stage gates to measure success, and manage uncertainty and risk in the development process [43]. NASA was one of the first organisations to break the development process into stages. This provided structure to the space program innovation process for component development, and allowed NASA to measure success and demonstrate progress through the TRLs. [44] [45] In the aerospace industry, many technologies such as the Airbus A350-XWB and its Rolls-Royce Trent XWB engines, are developed through rigorous stage-gated technology development processes in the form of a series of structured design reviews. The automotive industry, including companies such as Mercedes, have also applied this process to individual parts as well as overall vehicle performance to assess the maturity of products [46] [47].

For the ocean energy sector, the Wave Energy Scotland (WES) programme is an example of a stage gate process for ocean energy technology development [48]. The stage gate structure of the WES programme ensures that the most promising projects are chosen to progress through the stages to receive further support and funding. The evaluation of projects at each stage is shaped by metrics and stage gate criteria and reviewed through stage gate applications by a team of expert assessors. Technologies are required to outline their targets against the criteria, as well as describe a proposed scope of work towards achieving WES objectives. Through this programme WES has invested £30.9m and funded 84 contracts across 13 different countries. As partners in the consortium and leaders of the Stage Gate design tool work package, WES will enable DTOceanPlus to build on this world leading process and adapt it to include the whole of the project lifecycle for both wave and tidal energy technology. This will help ensure that DTOceanPlus Stage Gate design tool is built on processes that have been implemented in wider industry whilst harnessing specific ocean energy experience gained from developing a stage-gate structure, metrics and success thresholds.

Alongside WES, international efforts led by organisations such as the US Department of Energy, OCEANERA-NET and the IEA-OES are defining metrics and success thresholds for ocean energy technology development. This work is ongoing and the processes being developed are contributing to consensus on how success is measured in ocean energy technology development. Examples of these include:

- The US Department of Energy Water Power Technologies Office with the support of the National Laboratories have produced a document as part of a request for information (RFI) 'Existing Ocean Energy Performance Metrics' [49] which summarises existing performance metrics for ocean energy, and includes a wide variety of metrics which have been used to measure techno-economic potential to guide technology development.
- The IEA-OES Task 12 'Stage Gate Metrics for International Framework for Ocean Energy' [50] is working towards defining appropriate and rigorous metrics for measuring success in critical target areas of ocean energy technology development. The objective is to define a common international stage gate metrics framework to be used by a variety of stakeholders.
- The Ocean Energy ERA-NET has funded the progression of the stage gate metrics development through two workshops co-hosted by WES amongst others such as EERA Ocean Energy Joint Programme, Ocean ERA-NET and the IEA-OES [51]

While it is important that users can adapt the stage gate process to their own programmes, international consensus on metrics is valuable as it allows cross-funder comparisons. Different organisations working towards a common agreement for the method of assessing technologies and the associated success thresholds allows various funding organisations to learn from others, compare programmes, and avoid repetition and replication.

Outside of the ocean energy sector, there are several software packages for stage-gate processes, including:

- Stage-Gate® International with software Stage Gate Navigator™ which has been used for PepsiCo (drinks company), Kellogg's (cereal) and Lego [52]
- Gensight which has been used by Coca Cola [53]
- One2Team which has been used by Bic (stationary) and L'Oreal (hair products) [54]

These software packages are commercially available, with some providing servicing and support with setting up a stage gate process for new product development. There do not appear to be any open source software packages available, although some will offer a free trial for a limited time which can be cancelled within that timeframe. These packages generally include Microsoft Excel, PowerPoint or other templates for Microsoft Office packages with a stage gate structure in place, which a company can customise as appropriate. Others provide a unique software package to download, and are often linked with other project management processes like innovation roadmaps, portfolio management and best practises.

4.2 REQUIREMENTS FOR TOOLS TO ASSESS DEVELOPMENT STAGE

4.2.1 OUTLINE OF STAGE GATE DESIGN TOOL REQUIREMENTS

Table 4.1 presents the operational and functional requirements of the Stage Gate design tool.

TABLE 4.1: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF THE STAGE GATE DESIGN TOOL

	Description
Operational requirements	Enable technology development and support decision making to guide and assess the development of ocean energy technologies from concept through to deployment of sub-systems, devices and arrays.
Functional Requirements	1) Facilitate evaluation of the stage a device/technology is at within a stage gate metrics framework and identification of outstanding activities to reach next stage. 2) Utilise the Deployment and Assessment tools and the Structured Innovation tools to evaluate key parameters associated with sub-systems, devices and arrays. 3) Compare technologies' evaluation results with user-defined thresholds or standard benchmarks from the ocean energy sector and identify areas of shortfall. 4) Provide evidence for user's decision-making process through clear presentation and comparison of evaluation results.

1. Facilitate evaluation of the stage a device/technology is at within a stage gate metrics framework and identification of outstanding activities to reach next stage

The Stage Gate design tool will provide a structured framework within which technologies can be assessed and their performance can be measured. It will guide users of the tool to define a metrics framework, including suitable assessment metrics, stage entry criteria and thresholds. According to the user's particular benchmarks for success, these could be user-defined and/or defaults which are built into the software.

By allowing comparison of the user's status against a defined set of stage entry criteria, the Stage Gate design tool will facilitate evaluation of the technology development progress. This will guide users to direct their R&D efforts into the critical areas to progress through stages of development.

2. Utilise the Deployment and Assessment tools and the Structured Innovation tool to evaluate key parameters associated with sub-systems, devices and arrays

The Stage Gate design tool will assess sub-systems, devices and arrays at all technology development stages; from concept definition to deployment. The Stage Gate design tool will rely on the Deployment and Assessment tools to compute the appropriate stage gate metrics using data from the Digital Representation. Similarly, the Stage Gate design tool will interact with the Structured Innovation tool at early stages of technology development to execute assessment of early stage concepts through guided scoring of technical and economic characteristics. See more detail in section 4.2.5.2.

3. Compare technologies' evaluation results with user-defined thresholds or standard benchmarks from the ocean energy sector and identify areas of shortfall

By defining appropriate metric thresholds and comparing calculated metrics against them, users will be able to monitor achievement against their desired trajectory.

By highlighting areas which do not meet required metrics thresholds, technology developers will gain an understanding into areas where more R&D activity should be focused. This may highlight areas where the developer can use the Structured Innovation design tools which will assist them to identify improvement opportunities.

4. Provide evidence for user's decision-making process through clear presentation and comparison of evaluation results

The Stage Gate design tool is ultimately there to aid decision making and present complex information (in whatever level of detail is available), allowing users to understand the readiness and performance of a technology. Investors will be able to use this tool to understand key performance characteristics, compare technologies and support strategic decision making.

4.2.2 FUNCTIONALITY IN PRACTICE

A high-level description of how the Stage Gate design tool could be used in practice is outlined below for two of the use cases as defined in section 2.2.

Use Case 1: Technology developer

A tidal energy technology developer may require a structured method of assessing and measuring the performance of their tidal energy device throughout the technology development process, in order to demonstrate to potential investors, the progression of their technology performance towards critical targets. In this scenario, the technology developer could select a set of key stage gate metrics to measure the performance of their technology within the topic areas which are most relevant and important to a potential investor and best demonstrate the critical targets. Over the course of technology development, the user would then be able to track and display the progress in these key areas, with the uncertainty in the results decreasing as the availability and detail of the performance data increases through the stages.

Use Case 2: public and private investors

A private investor may have several technologies which they would like to choose between and the Stage Gate design tool could be used in this scenario to assist with this decision making. The user could decide to define their own bespoke stage gate metrics framework including the number of stages, the stage entry criteria and the metrics thresholds for each topic area. This enables a relative comparison of the technologies to be made. The flexibility of the Stage Gate design tool means that the user can select the metrics which are most important to them, and most appropriate to enable the comparison of technologies. For example, social acceptability may be weighted higher than conversion efficiency for that particular investor, meaning that they can receive an output of technology performance which is weighted higher against this topic area, to help with their decision-making process. See section 4.2.5.2 for this link between the QFD tool as part of the Structured Innovation design tool and the Stage Gate design tool.

4.2.2.1 OUTPUTS

The outputs of the Stage Gate design tool will be:

- The stage a technology is at within a specified stage gate metrics framework with user defined metrics thresholds.
- The distance to meet the next stage, highlighting areas where improvement is needed
- Individual breakdown of metrics and topic areas as required by the user

This information will be presented in various ways to support the user's decision-making process. Examples of these may include numerical tool outputs (against thresholds if required by user) in a range of visual formats for a specified number of technologies or for a single technology through numerous stage of the framework, including:

- Energy capture data displayed as matrices displaying power capture across a range of sea-states defined by bins of Significant Wave Height and Energy Period for a particular location (for wave energy) or power curve over a range of current velocities (for tidal energy).
- Spider charts displaying how a technology ranks in each of the topic areas.
- Bar charts showing comparisons with other ocean energy technologies
- Summary table for each topic area assessed within the framework with highlighted areas which fall short of thresholds
- Chart with technology development progression over time against key metrics as defined by the user

4.2.3 ADDRESSING USER REQUIREMENTS

In addition to the functional requirements outlined above, the user consultation provided some additional desired functionalities. The full table is in TN2.2 [5], and a summary of these points is listed here:

- Ability to reflect international best practises and accepted standards on stage gate processes and metrics frameworks
- Ability to adapt to the user's stage gate evaluation processes through:
  - Flexibility of stage definition
  - Flexibility of level of assessment detail to match information available at the technology maturity of interest
- Ability to evaluate technologies at very early stage when quantitative detail is not available
- Be quick to use at lower TRL levels
- Be compatible with other software packages
- Have flexible benchmarks of success in order to not favour any particular technologies
- Consider real deployment scenarios
- Fully compatible with other DTOceanPlus design tools

4.2.4 APPLICATION OF STAGE GATE DESIGN TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

4.2.4.1 USE THOUGHOUT PROJECT LIFECYCLE

At different stages in the project lifecycle, the data and information which is available for a technology will vary, with typically less data available at lower technology maturity levels, with increasing levels of detail and complexity as maturity increases. From the user consultation, it is clear that most users of the tool are expecting a tool which requires less detail and is quicker to use at an early stage, and similarly more detail and longer use time expected at later stages.

Early stage: There is likely to be some qualitative data and little quantitative data available about the performance of a technology. The Stage Gate design tool assessment method will be linked to the ability to work with the Structured Innovation, Deployment and Assessment tools to execute assessments at low TRL, by:

- Using fundamental engineering, physics and economics relationships through the high-level assessment of concepts as part of the Structured Innovation design tools.
- Simple, high level 'basic' quantitative assessments through the deployment and assessment tools. These can be the same as the detailed 'advanced' tools but with default values.
- Scoring of a technology by qualitative assessment using an expert assessor and clear scoring criteria.

Mid–Late stage: At mid–late stages in technology development there is likely to be more data available on the performance of a technology. Assessments can be done with high level 'basic' versions of the Deployment and Assessment tools with default values and/or simpler parameters, and as a technology matures, the full-complexity 'advanced' mode versions of the Deployment and Assessment tools will be used as detailed data is available. The level of data availability will determine the level of complexity of the tools which can be used, as illustrated in Table 2.2.

4.2.4.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

To address uncertainty and errors in the output of the Stage Gate design tool, the output will be presented with a 'confidence level' which will be based on several factors which indicate the quality of the input data. An example of some of these are:

- The use of default values; default values have a higher uncertainty than measured values.
- Test repetition; with data from repeated tests have higher certainty than a single dataset.
- Validation of numerical models; Numerical models which have been validated from test data has less uncertainty than an un-validated numerical model.
- The scale of the sub-system/device/array; smaller scale prototypes produce data with higher uncertainty than data which has come from full scale testing.
- Any other error bands which are output along with the data from the Deployment and Assessment tools or the high-level assessment from the Structured Innovation design tools.

4.2.4.3 APPLICATION TO SUB-SYSTEMS, DEVICES, AND ARRAYS

It is intended that the user of the Stage Gate design tool will select which level of assessment they require (sub-systems, devices and arrays) and the topic areas and metrics will be filtered accordingly, as some parameters will be defined differently for these different levels.

The Stage Gate design tool will rely on the Structured Innovation and the Deployment and Assessment design tools to compute appropriate parameters to assess technologies at all aggregation levels; sub-system, devices and arrays.

4.2.5 INTERFACES

4.2.5.1 GENERAL TYPES OF DATA TO BE CONSIDERED

The types of data will vary with the availability of data which will depend on the stage in the project lifecycle as described in section 4.2.4.2.

Early Stage example inputs may include:

- Description of main operating principles
- Material properties of the main components
- An outline of the likely failure modes.

Late stage example inputs may include:

- Test data from full scale sea testing
- Full analysis of failure modes with O&M model
- Bill of materials.

Whatever the stage in the project lifecycle, the general flow of data is seen in Figure 4.1 below.

The Stage Gate design tool will be compatible with the other DTOceanPlus suite of tools and be integrated to store and access data as part of the Digital Representation of Ocean Energy Systems.

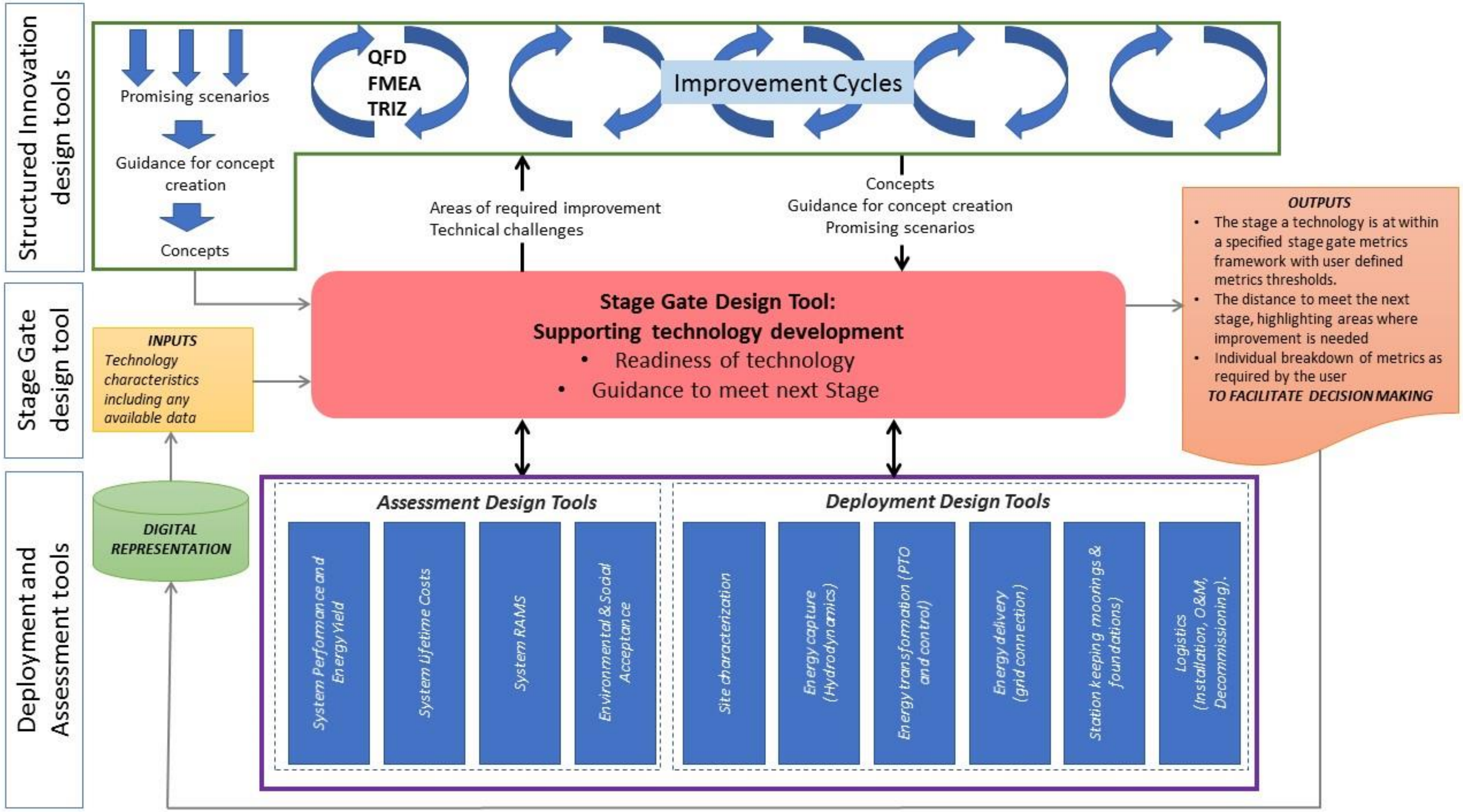

FIGURE 4.1: GENERAL FLOW OF DATA FROM INPUTS TO OUTPUTS FOR THE STAGE GATE DESIGN TOOL

4.2.5.2 REQUIREMENTS FOR OTHER DTOCEANPLUS TOOLS

Deployment and Assessment tools

The specific technical requirements of the Deployment and Assessment tools will be the parameters of the default stage gate metrics framework – these will be developed in the technical requirements.

The Stage Gate design tool will rely on the Deployment and Assessment tools to execute the calculations necessary to assess the performance of technologies. Therefore, there is a strong link between the outputs of the Deployment and Assessment design tools and requirements of the Stage Gate design tool.

As described in section 4.2.4.2, the Stage Gate design tool will utilise the Deployment and Assessment design tools at every stage of the project lifecycle if possible to do so. The requirement from these tools therefore is to assess each of the topic areas in both high level (less detailed) and in more detailed, complex calculations and feed the appropriate values back into the Stage Gate design tool.

Structured Innovation design tool

1) Since the QFD tool represents the 'voice of the customer' by taking user requirements and ranking them in order of importance, the user will be able to transfer these rankings to the Stage Gate design tool and use them to weight different topic areas appropriately. This will allow bespoke presentation of the outputs of the Stage Gate design tool according to the users' needs.

2) The earliest stage assessments (lowest TRL technologies) will require similar assessment processes as the Structured Innovation design tool, which is intended to assess concepts which are low TRL. The Stage Gate design tool will utilise these high-level assessment processes as appropriate for the earliest stage assessments, which as an example may include an indication of the cost of energy, reliability or environmental impact.

4.2.5.3 EXTERNAL INTERFACES

The Stage Gate design tool will be capable of interfacing with external tools and software packages (through the Global Database) which are intended to be used to provide an assessment of technology, depending on their ability to import/ export data. In particular, when any tools or software packages are utilised by the Deployment and Assessment tools or the Structured Innovation design tools, the Stage Gate design tool must be able to process the inputs and outputs of these to be used as part of technology assessment.

4.2.6 KEY LIMITATIONS OR EXCLUSIONS

- One of the key limitations of the Stage Gate design tool is that the metrics which can be assessed are limited to the assessments which can be made within the Deployment and Assessment tools. Anything which is outside of the scope of the Deployment and Assessment tools will not be assessed within DTOceanPlus.
- The quality of the output of the stage gate tool will be dependent on the quality of data which is input into the tool. The confidence level will reflect this.

- One of the suggestions from the User requirements document was that the Stage Gate design tool should identify a route to market for a user who is assessing their technology. Although it is intended for the Stage Gate design tool to highlight areas of improvement for a technology, this is where the performance falls short of a stage in a technology development process and will not directly be linked to potential routes to market, which is outside of the scope.

4.2.7 SUMMARY

The Stage Gate design tool will be used to aid decision making by displaying what stage in technology development a technology is at, and the distance to the next stage. The Stage Gate design tool will need to work very closely with the Structured Innovation, Deployment and Assessment tools in the assessment of technologies. The ability to assess technologies at both low and high TRL levels for sub-systems, devices and arrays is key to its functionality and reinforces the links between all the tools; Structured Innovation, Stage Gate, Deployment and Assessment design tools. Flexibility of how the tool is used was one of the key outputs of the user requirements study and is incorporated in this document.

5. DEPLOYMENT DESIGN TOOLS

5.1 INTRODUCTION AND CURRENT STATE-OF-THE-ART

The **Deployment Design Tools** will be used to support optimal device and array deployment. These tools will improve and expand on the capabilities of the original DTOcean software to consider the main functionalities of ocean energy technologies and systems, split into six modules, see table 5.1.

As discussed in section 1.3, the original DTOcean software is considered as state-of-the-art in terms of deployment tools for ocean energy. This integrated open-source software has the ability to provide optimal solutions for array design for wave and tidal energy deployments. DTOceanPlus will build on this functionality, incorporating user requirements identified in the consultation exercise.

The functional requirements produced for the deployment design tools to be developed in work package 5 are listed in the subsequent sections, starting with general requirements.

TABLE 5.1: DEPLOYMENT DESIGN TOOLS DEVELOPED IN WP5

Name	Task	Compared to DTOcean
Site Characterisation (e.g. metocean, geotechnical, and environmental conditions)	T5.3	New module
Energy Capture (at array level)	T5.4	Improved functionality
Energy Transformation (PTO and control)	T5.5	New module
Energy Delivery (electrical and grid issues)	T5.6	Improved functionality
Station Keeping (moorings and foundations)	T5.7	Improved functionality
Logistics and Marine Operations	T5.8	Expanded scope

5.2 GENERAL REQUIREMENTS FOR THE DEPLOYMENT DESIGN TOOLS

As with the overall DTOceanPlus suite, section 2.3, it is important that the Deployment Design Tools are easy to use, compatible with other tools, and offer flexibility in their use and level of detail.

The user consultation considered the Deployment and Assessment design tools jointly, as there is significant commonality between them. A key requirement from this were that these could be used to assess real deployment scenarios, including combined arrays of different devices and technologies. Calculation of lifetime costs was an important theme, including identification of cost reduction pathways, and providing evidence for funders and investors. Calculation of lifetime cost requires output from all the Deployment and Assessment design tools, highlighting the requirement for these to work together seamlessly.

The Deployment design tools will be updated from those in DTOcean, including improved design accuracy and management of uncertainty, and will take into account the latest research. New modules will fill identified gaps in DTOcean, namely Site Characterisation and Energy Transformation.

5.3 SITE CHARACTERISATION [T5.3]

5.3.1 OUTLINE OF SITE CHARACTERISATION TOOL

The Site Characterisation tool fulfils one of the first step of a project definition, which is defining the resource and environmental constraints. It can be used for a particular site to test a technology and develop a project or for a generic site in order to evaluate a turbine performance. This step is essential in every study and can also be conducted on its own with the goal of comparing different sites.

The Site Characterisation design tool is a new module in DTOceanPlus, filling one of the gaps identified in the original DTOcean toolset. The operational and functional requirements are set out in Table 5.2.

TABLE 5.2: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF SITE CHARACTERISATION TOOLS

	Description
Operational requirements	The Site Characterisation tool provides the characterisation of the environmental conditions at the farm's deployment site, by processing raw input data (bathymetry, wave regime, sea water level) and outputting processed data (current, wave statistics) to other DTOceanPlus tools and for user visualisation
Functional Requirements	1. Select the site location on the globe 2. Import the project site data 3. Edit site data 4. Generate characterised site data (Run current prediction solver or wave propagation solver on project area) 5. Export characterised data 6. Visualise site data

5.3.1.1 OUTPUTS OF THE TOOLS

As an output, the tool will visualise and provide to other tools, details of the site characterisation such as:

- Bathymetry data
- Coastline data
- Nautical chart data
- Maritime traffic
- Tidal data
- Swell data
- Wind data
- Constrained areas (protected areas, migratory areas ...)
- Characteristic properties of seabed

5.3.2 ADDRESSING USER REQUIREMENTS

Table 5.3 provides a summary of the requirements specific to the deployment and assessment tools from the user consultation survey and details how the Site Characterisation design tools aim to deliver them. Note that some of the higher-level user requirements from the DTOceanPlus suite of tools are discussed in following sections.

TABLE 5.3: KEY USER REQUIREMENTS FOR SITE CHARACTERISATION TOOLS

Requirements/feedback	Delivery
Long term resource assessment data could be imported	Import functionality will be included in the Site Characterisation tool.
Reliability and availability calculations	Site data critical to assess device fatigue and marine operation constrains will be imported or generated
Incorporating results from other software tools into the global database	The data generated by the Site Characterisation tool can be exported and saved in the database

5.3.3 APPLICATION OF SITE CHARACTERISATION TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

5.3.3.1 USE THROUGHOUT PROJECT LIFECYCLE

The Site Characterisation design tool will generate data to support the user in the assessment of the device and farm at early project stages where data availability may be very limited. Data generation will include simple constant current speed over the lease area and sinusoidal time variation. Coarse bathymetry layer will be made available by default.

For more precise time variation, the tool will enable import of harmonics from open databases (e.g. SHOM, NOAA, NODB). Similar functionality will be available for wave and wind with import from open hindcast models (Anemoc, Cefas, NOAA).

At later stage of the project, bathymetry and precise coastline data may be imported from standard numerical formats (data to be acquired by the user separately, or through a site survey), or using shape recognition of scanned nautical maps. It will then be possible for the user to refine the spatial variation of current and wave data using free surface hydrodynamic solvers (Telemac, Tomawac). Functionality to define detailed input parameters, boundary conditions and provide necessary pre-processing to generate underlying meshes will be available.

Functionality to import measurement data will be available to validate the site models.

Finally, at all stages, functionality to display site data on maps will be available.

5.3.3.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

A function that generates basic data, such as linearly varying bathymetry, and merges this with incomplete data will be created. This can be necessary because either the data is not available over the whole period of the study or some data points are missing (for example in the case of measurement data).

5.3.3.3 USE IN STRUCTURED INNOVATION AND STAGE GATE DESIGN TOOLS

At the earliest stages of technology development, the Structured Innovation and Stage Gate design tools may use data on classes of site which can be defined as part of the most basic mode of the Site Characterisation tool.

Site data will be part of the input data for the Deployment and Assessment tools which provide inputs for the Stage Gate design tool.

5.3.3.4 APPLICATION TO SUB-SYSTEMS, DEVICES, AND ARRAYS

Site data are mandatory inputs for all levels of aggregation; sub-systems, devices and arrays as it will inform the resource and input parameters for the other tools.

5.3.3.5 USE BY DIFFERENT USER ROLES

The different user types will have different needs and require different levels of tool complexity and detail. The different uses may be summarised in Table 5.4.

TABLE 5.4: USE OF SITE CHARACTERISATION DESIGN TOOLS BY DIFFERENT USERS

Technology Developers	Project developers	Public & Private Investors
▫ Perform a high-level assessment of the deployment site characteristics and how these would influence the performance of their technology ▫ Adapt the technology to different sites	▫ Scout different sites and their resource ▫ Fully assess a particular site to identify the most energetic zones, combined with the best locations in terms of bathymetry ▫ Start predicting how the environment will constrain the O&M phases and identify the potential main operational challenges to tackle (e.g. high waves or high currents in particular zones)	▫ High-level estimation of the site renewable energy resource availability in order to estimate site potential, Annual Energy Production (AEP) and project Levelised Cost of Energy (LCOE), ▫ High-level assessment of the site's wave climate in order to later estimate the associated project risks

5.3.4 INTERFACES

5.3.4.1 GENERAL TYPES OF DATA TO BE CONSIDERED

At the early development stages, there may be no site characterisation data available, and default data may be generated. Then for more detailed analysis, bathymetry input may be imported from bathymetry survey, as this data becomes available. This may be imported from scan of nautical maps, as well as detailed coastline. Detailed analysis of licence condition to include variables such as wave, wind and current speeds is to be carried out. These data may have to be downloaded as input data on user request.

5.3.4.2 REQUIREMENTS FOR OTHER DTOCEANPLUS TOOLS

The Stage Gate design tool will require default site characterisation data when there is no data about the site available at the earliest stages. Therefore, there must be a link between the Site Characterisation and Stage Gate design tools to ensure that any available data can be included where possible. Site data from the Site Characterisation tools will form an input to other DTOceanPlus tools.

5.3.4.3 EXTERNAL INTERFACES

External interfaces to easily download data from NOAA, NODB, Anemoc, SHOM will be available.

5.3.5 KEY LIMITATIONS OR EXCLUSIONS

The main limitations could come from the complexity of using real (potentially limited) field data and from having to work on a significant number of scenarios in order to have acceptable statistical results. Moreover, not all the necessary inputs may be in the public domain and this tool does not include the research of such parameters.

5.4 ENERGY CAPTURE [T5.4]

5.4.1 OUTLINE OF ENERGY CAPTURE TOOLS

The Energy Capture tools estimate the Annual Energy Production (AEP) of a given array layout of Tidal (TEC) or Wave (WEC) Energy Converters by solving the underpinning hydrodynamic interactions within the array, achieving a workable compromise between computational speed and accuracy. The tools can additionally be used to estimate the array configuration that maximise the AEP. In the following table, the Operational and Functional requirements of the Energy Capture tools are summarised.

TABLE 5.5: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF ENERGY CAPTURE TOOLS

	Description
Operational Requirements	Identification of the energy (maximum) yield from an array of either Tidal (TEC) or Wave (WEC) Energy Converter.
Functional Requirements	1. Asses different possible placements of TECs/WECs within the Lease Area based on the site conditions and the description of the deployed technology 2. Identify the best configuration. Where the term "best" can vary depending on the overall objective and metrics.

5.4.2 ADDRESSING USER REQUIREMENTS

Several user needs for the Energy Capture tool have been identified through the user consultation survey. The main outcomes of the user requirements consultation are summarised below:

(i) The most likely stages in which the Deployment and Assessment tools are to be used are in concept selection and feasibility studies
(ii) Even though accuracy is appreciated, the phase requiring most accuracy is the design stage. Additionally, the user is expecting to spend from some hours to a few days building the model and they are going to do themselves rather than sub-contracting.
(iii) Deployment and Assessment tools are very well understood so far and very likely to be used by a broad range of user types, from 'policy makers and regulators' to project developers
(iv) Usability is appreciated together with modularity
(v) Deployment and Assessment design tools are most important at array or device level rather than subsystem level
(vi) Interfacing with most commonly used software is very appreciated, such as Microsoft Excel, Matlab and Python, as well as other specific software packages such as ANSYS or Orcaflex. Numeric output files for ease of including results in reports is also valuable
(vii) The Deployment and Assessment design tools should calculate key parameters which help enable comparison of technologies and bankability of projects.

The tools are desired to be reasonably accurate at early phases of the project lifecycle. Identified user needs point at focusing the efforts of the Energy Capture tools at the concept and feasibility studies (i). The level of detail required should ideally be enough to provide statistical properties of the absorbed wave with a reasonable uncertainty level (ii).

The tools should be easy to use (iv). The Energy Capture tools, being included in the Deployment and Assessment set of tools, are better understood than other sets of tools; the inclusion of this module should be kept simple (iii). Not requiring very detailed information is aligned with the requirement of spending some hours to a few days for inputting data (ii).

The tools are expected to capture the globality of the project. It is likely to represent the overall performance of the project mostly at array level and then at device level (v). It should allow technology comparison and facilitate for cost reduction (vii).

These tools should be capable of interfacing with most of processing tools. Outputs of this module may be extracted with the level of detail required by the user through the digital model representation (vi).

A comprehensive extract of requirements for the Energy Capture tool from the user consultation is given in TN2.2 [5].

5.4.3 APPLICATION OF ENERGY CAPTURE TOOLS AT DIFFERENT LEVEL OF COMPLEXITY

5.4.3.1 USE THROUGHOUT PROJECT LIFECYCLE

In order to reflect the need for different model complexity at different project stages, as detailed in the analysis of user needs, the Energy Capture tools could be divided into few sub-tools, starting from a simple analytical model, with low accuracy to be used in the concept definition, to the full numerical model to be used in the later project stages. This will go along with the time requirement both for input formatting/completeness and computational cost.

TABLE 5.6: USE OF THE ENERGY CAPTURE TOOLS AT DIFFERENT STAGES IN THE PROJECT

Stage	Data Availability	Assessment Method
Early	Little information on the system	Scoring technologies and layouts based on simple metrics to output mostly qualitative data.
Mid	Immature and incomplete quantitative data	Utilisation of prebuilt classes to output quantitative data.
Late	Mature and complete quantitative data	Full analysis

5.4.3.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

For the early stages, data availability will be limited and simplified assessments will be necessary.

Simplified power curves and/or power matrices can be used together with the information of the average energy at the location. This would reduce the data input requirement to a minimum, but also increase the output uncertainties.

5.4.3.3 USE IN STRUCTURED INNOVATION AND STAGE GATE DESIGN TOOLS

The Energy Capture tools can be used in both Structured Innovation and Stage Gate design tools to estimate technology potential and to compare different technology types.

5.4.3.4 APPLICATION TO SUB-SYSTEMS, DEVICES, AND ARRAY

The Energy Capture tools can be used to assess the Annual Energy Production (AEP) for both Tidal and Wave Energy Converters at both array and device level.

No application to sub-system is foreseen.

5.4.3.5 USE BY DIFFERENT USER ROLES

The use by different role can be well align with the project stage and accuracy requirement.

- At early stage, high-level functions assessing the energy capture can be used based on simplified power curves and/or power matrices. There would be a link here to the Structured Innovation design tool in the high-level assessment of concepts.
- When more data is available, at a mid-stage of technology development, the Energy Capture tool would be assessed from running the tool in 'basic' mode with the optional use of simple parameters and/or default values for some of the key variables which are missing.
- When all required data is available then the tool can operate in 'advanced' mode for the highest detail (lowest uncertainty) for the assessment.

TABLE 5.7: USE OF ENERGY CAPTURE DESIGN TOOLS BY DIFFERENT USERS

Technology Developers	Project developers	Public & Private Investors
▫ Device developers will be interested in performing a high-level assessment of the capture width of a device, in order to evaluate their technology	▫ Project developers could be interested in using the tools at every project stage. Starting from the high-level estimation if site or technologies are to be compared, all the way down to full analysis if the concrete array design is needed.	▫ High-level estimation of the AEP in order to assess the potential of the ocean energy system.

5.4.4 INTERFACES

5.4.4.1 GENERAL TYPES OF DATA TO BE CONSIDERED

The Energy Capture tool requires two main inputs: the first one describing the site (output of the Site Characterisation tool), including bathymetry, lease area, metocean conditions, etc.

The second input is the description of the device. This can be as simple as a device type, all the way down to the full device description, such as Power Curves, Geometry, etc.

5.4.4.2 REQUIREMENTS FOR OTHER DTOCEANPLUS TOOLS

The Energy Capture tool will require input from the Site Characterisation tool such as bathymetry, and metocean conditions. Data on technology characteristics are also fundamental inputs which may be partially inserted by the user at the interface level and partially output from the single machine analysis. The single device analysis output could be provided by the user using external software.

5.4.4.3 EXTERNAL INTERFACES

The Energy Capture tools will interface with standard linear potential theory software such as WAMIT and AQUA, importing/exporting data via standard formats. Due to the expected modularity of the code, it should be possible to replace the Energy Capture tools with custom user tools, as long as the data output formatting is kept aligned with the DTOceanPlus standards.

5.4.5 KEY LIMITATIONS OR EXCLUSIONS

Both Tidal and Wave sub-modules are associated to several assumptions that limit the results' accuracy. Code verification and validation have been carried out in the DTOcean project, but increased accuracy would result in unfeasible computational cost as expressed in the user consultation. Therefore, coupling with Computational Fluid Dynamics (CFD) or Smoothed-Particle Hydrodynamics (SPH) software is not considered applicable to DTOceanPlus since the user will not be willing to spend more than 2 weeks on tool preparation and operation.

Applicability to variable bathymetry cases (wave energy) need to be investigated, due to the limited development time within the project lifetime. While the implementation of variable bathymetry for tidal energy is somehow limited to empirical formulas.

5.5 ENERGY TRANSFORMATION (PTO & CONTROL) [T5.5]

5.5.1 OUTLINE OF ENERGY TRANSFORMATION TOOLS

These tools will deal with the processes inherent to the energy transformation, i.e. including energy conversion by the **Power Take-Off** (PTO) and the associated **Control Strategies**, which was identified to be a gap in DTOcean. The operational and functional requirements of the energy transformation tool are introduced in Table 5.8.

TABLE 5.8: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF THE ENERGY TRANSFORMATION TOOLS

	Description
Operational requirements	Assess and optimise PTO technologies and associated control strategies at varying levels of complexity throughout the project lifecycle
Functional Requirements	1. Assess the efficiency of common (and eventually user-defined) PTOs and control strategies for a specific ocean energy system 2. Assess component costs and loadings

5.5.2 ADDRESSING USER REQUIREMENTS

The user needs for the Energy Transformation tools identified through the user consultation survey [6] are consistent with those for the Energy Capture tools presented in section 5.4.2.

It was requested that energy storage be included within DTOceanPlus. While this is outside the scope of the project, it will be considered and included if possible, as storage is an important consideration for renewable energy projects.

5.5.3 APPLICATION OF ENERGY TRANSFORMATION TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

5.5.3.1 USE THROUGHOUT PROJECT LIFECYCLE

The Energy Transformation module is very likely to be based on stochastic approaches since **concept definition** and **feasibility** studies will be the most demanded stages of development, here defined as **early and mid-stages**. Still these stages need to be homogeneous to avoid inconsistent results and erroneous conclusions. Generally, the Deployment design tools were well understood among DTOcean users, and it is expected that also the users of DTOceanPlus will understand the usage of the Energy Transformation Tools. In general new features and higher complexity can be implemented if the GUI makes it understandable. It should be clear enough about the desired level of detail against the required information.

Early stage: *The tools will be fast, to compute high-level assessments with less detail.* Consider using frequency domain analysis only. Global approximations of the efficiencies will be applied based on previously assessed simulations and the scale of the device.

Mid stage: *At this level, the tools can run a bit slower than for the concept definition as a higher level of complexity is required.* Efficiencies of different sub-systems to be provided to the user, cut-in and cut-off power level may be defined

Late stage: *Here, accuracy is more important than speed.* Include possible non-linearities resolved in time domain. Since stochastic approaches are based in linear models the most accurate results should be based on previous linearisation of non-linear effects by the most advanced users such as project developers (i.e. real-time control strategies) and including their properties into a global set of data and custom user functions enabled for that purpose.

5.5.3.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

At the early stage when less is defined about a sub-system, device or array, the assessment of the Energy Transformation may be computed in the following ways:

- High level calculations for efficiency based on fundamental relationships between PTO type, efficiency and energy yield. There would be a link here to the Structured Innovation design tool in the high-level assessment of concepts.
- If more data is available such as the types of control/PTO/generator/power electronics, the uncertainty in the assessment would decrease and the assessment could be based on the 'basic' mode of the Energy Transformation tool with the optional use of default values for some of the key variables which are missing.
- If all required data is available then the tool can operate in 'advanced' mode for the highest detail (lowest uncertainty) assessment

5.5.3.3 SUB-SYSTEMS, DEVICES, AND ARRAYS

Subsystems are to be considered in feasibility studies within the energy transformation tool as previously pointed out. Performance of each of them is to be assessed depending on the operation mode of the tool, i.e. in **concept definition** the efficiency may be directly applied to the energy production of the previous subsystem whilst **in feasibility studies** efficiencies are applied to each power level with its own probability.

The outputs could be visible at various levels of aggregation, as this is a prerogative of the digital representation of ocean energy systems proposed in DTOceanPlus.

When designing the tools, it is important to have in mind the compatibility of the PTOs and control strategies. The segmentation of PTO technologies should allow only feasible aggregations of prime mover (hydrodynamic to mechanical power) and electrical generation (from mechanical to electrical power). This also applies for control strategies. Indeed, not all controls are compatible for every PTO (e.g. reactive control for air and hydro turbines in Wave Energy Converters).

5.5.4 INTERFACES

5.5.4.1 GENERAL TYPES OF DATA TO BE CONSIDERED

For each sub-system, two types of data are to be specified: (i) the minimum expected data are the mandatory ones and can be associated to the **concept definition phase**; and (ii) the additional, or detailed, data are those required in **feasibility phase** for better accuracy. The highest-level and lower level tentative inputs may be:

Minimum expected variables:

- Type of control strategy
- Type of PTO
- Type of generator

Additional/detailed variables (parameters of each sub-type enabled):

- Type of Control strategy (Passive loading, Latching, Reactive control, User defined strategy, etc.)
- Type of PTO (Air turbine, Mechanical PTO, Direct drive, User defined PTO, etc.)
- Type of Generator (Induction generator, Permanent magnet, Linear generator, User defined generator, etc.)
- Power electronics
- If energy storage is implemented: Type of Energy storage system (Hydraulic reservoirs, Kinetic storage, Chemical battery pack, Super capacitors, User defined, etc.) – see note on energy storage in section 2.3.2.

For design purposes, the main parameters of each sub-system may be optimised so that the highest mean annual electrical power output is found. An output of this tool is the **PTO efficiency** η_{PTO}, defined as the product of the different component efficiencies $\eta_{cmpt,n}$ where the number and type can be specified as, for example, mechanical and electrical only or add more detail when available.

$$\eta_{PTO} = \eta_{cmpt,1} \cdots \eta_{cmpt,n}.$$

When the PTO efficiency does not describe fully the behaviour of the PTO system (e.g. in case of reactive control), other metrics may be added.

5.5.4.2 REQUIREMENTS FOR OTHER DTOCEANPLUS TOOLS

Required inputs by the Energy Transformation tool come mainly from the Energy Capture module (T5.4). Depending on the accuracy level, hydrodynamic power per sea state with its probability or spectra of hydrodynamic velocities and forces may be required.

5.5.4.3 EXTERNAL INTERFACES

Interfaces with external libraries of PTOs should be explored so that users can import data from them in standard formats, such as PTO-sim code.

5.5.5 KEY LIMITATIONS OR EXCLUSIONS

This tool is supposed to work with data provided mainly from the Energy Capture module. Therefore, its objective is to represent the assumed influence of the PTO on the hydrodynamic performance. If an outer loop of optimisation, requiring feeding back the hydrodynamics module, is to be carried out, it is left to be done by user via the main module.

The tool performs technical analysis/design with the objective of finding ways to locally maximise the energy output. Also, the tool should include the analysis of component loadings but detailed study of reliability, maintenance needs and availability will be carried out in other tools.

5.6 ENERGY DELIVERY (GRID ISSUES) [T5.6]

5.6.1 OUTLINE OF THE ENERGY DELIVERY TOOL

The Energy Delivery tool designs and assembles optimal solutions for the electrical infrastructure, which delivers electrical power to the onshore distribution network, for a given sub-system, device, array and site. The design objective of the tool is to maximise the level and quality of the delivered power considering the cost and value of the solution proposed, as well as to ensure overall grid compliance. The term 'electrical infrastructure' includes all the key electrical components such as the umbilical cable, static subsea intra-array cables, electrical connectors, offshore collection points, and the transmission cables to the onshore grid. A simplified schematic of the main three connected sub-systems (shown within the dashed box) that constitute the electrical infrastructure is shown in Figure 5.1.

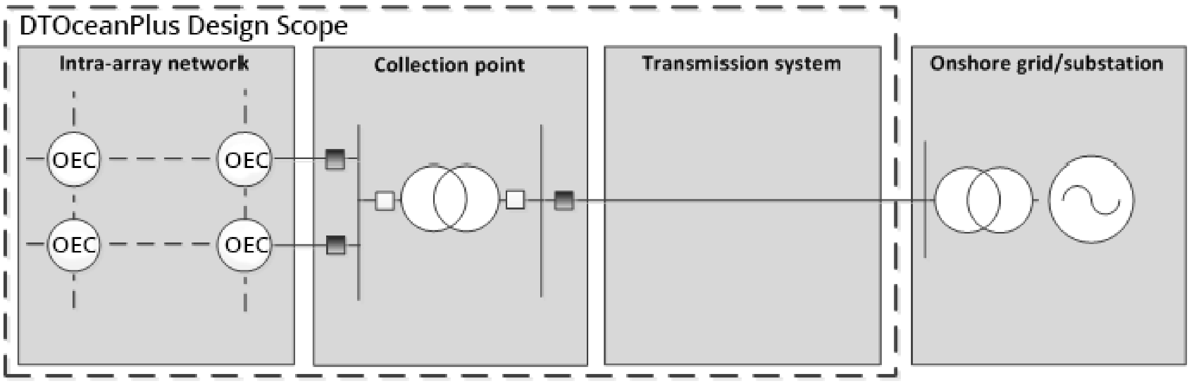

FIGURE 5.1: SIMPLIFIED GENERIC OFFSHORE ELECTRICAL NETWORK FOR OCEAN ENERGY ARRAYS

The design and assembly of the electrical infrastructure will typically move from the onshore electricity network towards the offshore sub-system, device or array. The operational requirement of the Energy Delivery tool will be delivered by a number of discrete functions which are summarised in Table 5.9 and explained in detail below.

TABLE 5.9: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF THE ENERGY DELIVERY TOOLS

	Description
Operational requirements	To design and assemble optimal solutions for the electrical infrastructure for a given sub-system, device, array and site.
Functional Requirements	1. Process the seabed information 2. Design the transmission system - including cable routing and collection point design 3. Design the intra-array network - including cable routing and collection point design 4. Select and identify appropriate components based on the designs 5. Evaluate technically feasible solutions using a techno-economic model

1. Process the seabed information

Seabed information including bathymetry, exclusion zones, maximum seabed temperatures, maximum soil resistivity, seabed gradients and the type of soil/rocks that constitute the seabed are processed first both for the lease area and for the cable corridor area. This information is then used to identify possible cable routes and cable protection options both for the intra-array network and the transmission system.

2. Design the transmission system – including cable routing and collection point design

The design of the transmission system includes the selection of the transmission voltage, the capacity and the number of transmission cables to the shore, optimal cable routes to the onshore landing point and protection requirement for these cables. The transmission voltage/export voltage is normally set based on the size of the device/array, the distance of the collection point(s) from the shore and the onshore network characteristics. The capacity of the transmission system and the number of cables to the shore are a function of the power rating of the device/array, the length of the cable, redundancy requirements, the maximum seabed temperatures, maximum soil resistivity etc. An optimal cable route is determined using a shortest path routine including constraints like gradients between all neighbouring grid points.

3. Design the intra-array network - including cable routing and collection point design

This tool requires details of the device and array from the user or from other modules, such as the device type, rated power, rated voltage, power factor, connector type (wet mate or dry mate), connection point, array layout, and array output.

The main design decision to be taken by the tool is whether the intra-array network takes up a radial, star or hybrid structure, which is made based on the array layout, the number of devices in the array and the power and voltage ratings of the device. In the star structure, the devices are intelligently clustered and connected to local collection points. These local collection points may then be connected to a central collection point from which the export cable to the shore runs. Having separate export cables to the shore from all the local collection points may also be a viable solution depending on the stage at which the array deployment is and for redundancy.

Cable routing within the intra-array network follows a similar principle to the routing of the export cable.

4. Select and identify appropriate components based on the designs

After the intra-array network and the transmission system have been designed, the electrical components database is accessed. This database consists of eight individual component tables for the main electrical components of an offshore network: static cables, dynamic cables (umbilicals), wet-mate connectors, dry-mate connectors, collection points, switchgear, transformers and power quality equipment. From the database, the electrical components appropriate to the network design are chosen and assembled. There may be more than one solution possible at this stage and all these technically feasible solutions are saved and displayed to the user.

5. **Evaluate technically feasible solutions using a techno-economic model**

The last tool compares the technically feasible solutions that have been identified in the previous step. This involves a techno-economic analysis of the solutions and the local best solution is obtained by comparing the overall network efficiency (i.e. network losses) and component costs. The costs of electrical infrastructure, including the component cost, the cost associated with the losses in the network and the costs due to failures will be evaluated. Once the techno-economic analysis is completed an optimal electrical infrastructure assembly will be determined by the tool.

Outputs

The Energy Delivery tool displays the following data after the electrical infrastructure optimisation is complete:

1. Annual yield – the annual yield at the onshore landing point
2. Bill of materials – a summary of the economic data
3. Component data – a table with information of all the components, their location coordinates, their quantities/lengths.
4. Network design – including the connections between the different sub-systems, the cable routes of the inter-array network and the transmission system, collection point(s) design data and umbilical cable design data.

5.6.2 ADDRESSING USER REQUIREMENTS

The requirements specific to the Deployment and Assessment design tools from the user consultation survey are listed below. They have been divided among four broad themes. Details of how the Energy Delivery tool aims to deliver these user requirements are discussed in this section.

1. High level requirements
    a. Capability of assessing devices and locations
    b. Possibility of analysing combined arrays of different devices types and technologies
    c. Reliability and availability calculations
    d. Addressing gaps in state-of-the-art
2. Tool objectives
    a. Evaluation of energy yield and maximising energy delivery
    b. Minimising Levelised Cost of Energy (LCOE)
    c. Identification of cost reduction pathways
3. Technical requirements
    a. Additional collection point options
    b. Multiple cable installation methods, including cable lay on the seabed
4. Data/module/tool interlinkages and exchange
    a. Data/results exchange
    b. Interlinkages between the tools to form an integrated package
    c. Accessing and running analysis from each tool/module independently
    d. Incorporating results from other software tools into the global database
    e. Importing long term resource assessment data

1. High level requirements

The DTOceanPlus Energy Delivery tool will be based on the Electrical Sub-Systems module in DTOcean, which is the state of the art tool in this area. The new tool, though, will also include the consideration of new topologies (e.g. multiple export cables), intelligent clustering of devices and improved cable routing algorithms. Detailed design of dynamic (umbilical) cables will be provided to incorporate the mechanical design aspect of the cable in addition to the electrical design aspects.

The main sub-systems in the electrical infrastructure are shared by most types of devices and is technology neutral apart from minor modifications that may be required. Therefore, the Energy Delivery tool will have the capability to be used with both devices of different types and arrays of devices with ease. The tool works on device information (device type, rating etc.) provided by the user or output from the other modules. Thus a facility to specify this information for every device in an array will be included in the tool. This feature will allow arrays of different device types to be analysed, which is relevant since the MeyGen project, which is one of the first tidal arrays to be deployed, is a collaboration between two tidal developers.

The electrical infrastructure and components for marine devices and arrays are similar to those used in offshore wind farm and in the oil and gas sector. Reliability data of the different components from these sectors will be used initially, until the time when this data is available from ocean energy deployment.

2. Tool objectives

The overall objective of the Energy Delivery tool is to propose optimal electrical infrastructure for a device or an array including both technical and economic considerations. The technical considerations include energy yield, which is also an output of the tool. The overall objective of the suite of DTOcean Plus tools is to minimise the LCOE of the entire system.

The Energy Delivery tool as an output will list the bill of materials, which will also include the costs due to failures and losses of all the different components in the electrical infrastructure. This might indicate areas where costs are high and cost reduction maybe possible. That said, within the electrical infrastructure, the possibility of having significant cost reductions due to developments in technology is low. Cost saving may come from devices/arrays sharing the infrastructure and with more efficient installation, operation and maintenance effort.

3. Technical requirements

The DTOcean tool was developed keeping early stage arrays in mind and hence every optimal solution it proposed had a substation/collection point. Since the scope of the DTOceanPlus suite of tools is wider and includes devices/arrays in various stages of development, additional collection point options will be included. Having no collection point, but running cables back to shore individually from every device for very early arrays will be included as well. How the cable is laid/buried in the seabed and if any cable mattress protection is provided to the cable on the seabed will be a user input in the Energy Delivery tool.

4. **Data/module/tool interlinkages and exchange**

The suite of DTOcean Plus tools are designed in a modular fashion, which allow them to be used independently on the one hand. On the other hand, the different tools within the suite will be interlinked to form an integrated package, which is the ultimate objective of this project. The individual tools and the suite will have options for data/results exchange in common formats. For example, within the Energy Delivery tool this is particularly relevant in reliability/failures data. Such data from other software tools may be incorporated into the global database.

5.6.3 APPLICATION OF ENERGY DELIVERY TOOL AT DIFFERENT LEVELS OF COMPLEXITY

5.6.3.1 USE THROUGHOUT PROJECT LIFECYCLE

The Energy Delivery tool will be developed keeping in mind the requirement for use at different stages of project lifecycle and at different levels of complexities. This includes use during different stages of both development and deployment. As can be expected, the level of available data and information and the general complexity of the tool will be lower at an early stage. This will allow high-level, faster analysis with the tools. Before running the Energy Delivery tool, the users will be given the choice to select a simpler 'basic mode' or a more detailed 'advanced mode'. Additionally, for all the inputs required in the advanced mode, informed default values will be provided, which the user may select if the information required is not currently available.

A list of possible simplifications/default values that can be used with the Energy Delivery tool are listed below. Note that this is not an exhaustive list of all the possible simplifications that will be developed as a part of the Energy Delivery design tool.

1. The rated power of the OEC can be used to design current ratings of the electrical components in cases where histograms of device/array power output are not available.
2. The shortest distance between two subsea points and/or the onshore connection point can be assumed to be the cable route in case subsea data is not available. The length of cable required can be 20-30% higher than the shortest distance to make the value more realistic.
3. The mechanical properties of the umbilical cables can be ignored initially when the only objective is to study power flow.
4. DC power flow solutions may give an indication of power flow and component ratings required, without the more complex AC power flow, which also considers reactive power flow.
5. Intra-array network design may be simplified by lumping converters in strings rather than considering them individually.

5.6.3.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

As mentioned in the previous section, all the input parameters for the Energy Delivery tool will have typical default values available in case of missing or incomplete data. The tool will inform the user of increased uncertainties in the results when these default values are used. A facility that allows sensitivity analysis to be carried out over parameters will be included, which will indicate the significance of the value of a parameter to the optimisation problem.

5.6.3.3 USE IN STRUCTURED INNOVATION AND STAGE GATE DESIGN TOOLS

The Energy Delivery tool will ensure that an optimal electrical infrastructure is used when holistic assessments of technology/TRLs are made using the Structured Innovation and/or the Stage Gate design tools.

5.6.3.4 APPLICATION TO SUB-SYSTEMS, DEVICES, AND ARRAYS

The Energy Delivery tool will be equally applicable for single devices and for both small and large arrays. The main sub-systems of the electrical infrastructure are similar for both devices and arrays. When accurate cost models and power flow solutions are used in the optimisation, the optimal solutions proposed by the tool will be appropriate to the stage of deployment of the device or array.

5.6.4 INTERFACES

5.6.4.1 GENERAL TYPES OF DATA TO BE CONSIDERED

The Energy Delivery tool requires the following types of data:

1. Geophysical and geotechnical data of the seabed
2. Electrical data (voltage, current, power, impedance) of the components
3. Mechanical properties of certain components like umbilicals and connectors
4. Power performance/characteristics of the device/array
5. Costs of the different electrical components

5.6.4.2 REQUIREMENTS FOR OTHER DTOCEANPLUS TOOLS

The Energy Delivery tool requires the following data/features from the other DTOceanPlus design tools:

1. Geophysical and geotechnical data of the seabed from the Site Characterisation design tool.
2. Power performance/characteristics of the device/array from the Energy Transformation design tool.
3. Reliability and failure data for the electrical components from the System RAMS design tool.
4. Economic assessment to be carried out in collaboration with the System Lifetime Costs design tool

5.6.4.3 EXTERNAL INTERFACES

Interfaces for input/output of data with industry power flow software will be provided to allow users to make best use of existing resources.

5.6.5 KEY LIMITATIONS OR EXCLUSIONS

High Voltage DC transmission from the collection point(s) to the onshore network or within the intra-array network will not be considered in this project and is considered to be an enabling technology. HVDC transmission will be required for bigger wave and tidal energy farms further away from the shore than those that would be seen in wave and tidal sector in the medium term.

5.7 STATION KEEPING (MOORINGS AND FOUNDATIONS) [T5.7]

5.7.1 OUTLINE OF STATION KEEPING DESIGN TOOLS

The Station Keeping design tools will support the design of the mooring and foundation subsystems. The tool will deal with the full design of gravity foundations, piles, anchors, mooring lines, mechanical design of the dynamic umbilical cable and its interaction with the other elements of the mooring system. The techno-economic approach will allow an automated design process and the fast design and selection of the best technology for the farm configuration.

The models of the original version of DTOcean will be improved with further functionalities to strengthen the connection with the other modules. For instance, handling the positioning of the gravity foundations and anchors given the bathymetry description and the possibility of accounting for novel layout configuration (shared foundations/anchors, new line type, etc.). In addition, functionality to import/export standard data formats with commonly used commercial software (i.e. Orcina's Orcaflex or Principia's Deeplines) should be designed and implemented in order to provide a comprehensive design solution covering the full range of the device and farm development and deployment.

The operational and functional requirements of the Station Keeping tools are summarised in Table 5.10. Some potential routes of enhancement are presented in TN2.2 [5]. Sub-function improvements are proposed for each main function, without prioritisation. Those proposals will be further developed and analysed during the task T5.1 "Technical requirements of the Ocean Energy development tools".

TABLE 5.10: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF THE STATION KEEPING TOOLS

	Description
Operational requirements	Design the Station Keeping system. Support the decision-making process by providing validated cost-optimised design options for the Station Keeping systems
Functional Requirements	1) Modelling of the Station Keeping system Faithfully represent the Station Keeping system based on appropriate models with respect to the desired level(s) of fidelity. Those models are: Load models, umbilical models, mooring line models, motion solving models (frequency or time-domain) and foundation models 2) Definition and optimisation of the Station Keeping system Propose design alternatives based on the proposed site/technology and following techno-economic criteria 3) Support the decision-making process Provide the users with the design options and let them select the best solution or run additional computation to test other alternatives

5.7.2 ADDRESSING USER REQUIREMENTS

From the user consultation, the main user needs related to the Station Keeping tools can be summarised as follow:

1. Minimising Levelised Cost of Energy (LCOE) instead of maximising Annual Energy Production (AEP)
2. Addressing the DTOcean gaps where most value can be added to the sector
3. The tool should be dedicated to initial assessments only
4. Software compatibility with third party commercial software
5. Identification of cost reduction pathways
6. Providing application programming interface (API) for external programming / Automating tasks to allow batch runs or sensitivity analysis

As for the first point of the above list, the LCOE optimisation will be dependant of the inter relations possible between the Deployment and Assessment design tools. This will be further developed during the technical requirements tasks of the project (T5.1 and T6.1).

Points 2 to 4 can be achieved by providing easy communication between the DTOceanPlus Station Keeping design tools and the most popular Station Keeping software. Indeed, those tools are usually available to the users, e.g. Technology Developers, or Project Developers (sub-contractors), and no added value would be brought by adding functionalities already available in those tools. Similarly, those tools are needed for detailed design, thus specifically answering the point 3 advising DTOceanPlus to focus on early stages of development.

The identification of cost reduction pathways (point 5 above) could be achieved through linkage of Assessment design tools and the Structured Innovation tool.

Finally, the API programming and the automation of task running is to be further developed, especially in conjunction with the linkage to third party software which are typically high-fidelity models with large computation time.

5.7.3 APPLICATION OF STATION KEEPING TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

5.7.3.1 USE THROUGHOUT PROJECT LIFECYCLE

Referring to the definitions in section 2.1.2, the station keeping module is mainly concerned with the design phase, ensuring the survivability of the systems and sub-systems during the operation phase (including maintenance). This design phase can be seen through the three stages defined in Table 2.1 and the associated module "modes" from Table 2.2.

- At early stage, high-level functions describing the moorings and foundations could be used based on fundamental physics of the loads expected. This would be linked to the Structured Innovation design tool in the high-level assessment of moorings and foundations concepts

- When more data is available, at later stages of technology development, the Station Keeping module would be generated from a 'basic' mode of the Station Keeping module with the optional use of some functionalities and/or default values for some of the key variables which are missing (e.g. neglecting anchor or umbilical design if soil data or umbilical specification is not available as for optional use of functionalities)
- When all required data is available then the module can operate in 'advanced' mode for the highest detail (lowest uncertainty) for the design.

For the latter stages of development (higher TRLs), clearly the capabilities of a comprehensive design tool such as DTOceanPlus are not meant to provide detailed engineering design information. In this context, the new functionality of connectivity with third-party software (e.g. Orcaflex, DeepLines...) could provide the right solution by providing interfaces with commonly used tools used by the industry with high-fidelity modelling capabilities.

It is to be noted that even at the earliest stages of design, the (very) dynamic nature of ocean energy systems encourages the use of high-fidelity models, even with incomplete data.

5.7.3.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

The default database should cover classical mooring components as these are well standardised from the Oil and Gas industry. Innovative components could be covered by making some linkage with the Structured Innovation and Stage Gate Tools, and by letting the user input its own technology characteristic values.

Unavailability of other input data, such as metocean or soil data should be addressed consistently across other modules, such as the new Site Characterisation module, by providing links with freely available databases and typical default values for physical inputs like soil data based on soil type. In this case, some warnings are needed to alert on the low reliability of the used data.

5.7.3.3 USE IN STRUCTURED INNOVATION AND STAGE GATE DESIGN TOOLS

The Station Keeping module will indirectly feed in the Stage Gate tools through the evaluation metrics provided by the Assessment tools, themselves based on the outputs (e.g. bill of materials, mooring layout) provided by the Station Keeping module.

Identification of weak components during the Station Keeping design process could feed the Structured Innovation tools. This will be developed during the Technical Requirements generation process through collaboration between the tools / modules.

5.7.3.4 APPLICATION TO SUB-SYSTEMS, DEVICES, AND ARRAYS

The tool primarily addresses the mooring and foundation sub-systems. Potential additional device and array functionalities could be the linked with the Energy Capture module such as foundation location selection driven by the bathymetry and shared foundations design capabilities.

Some additional sub-system applications might arise from interactions between the Structured Innovation tools and the Station Keeping module by the identification of weak components.

5.7.3.5 USE BY DIFFERENT USER ROLES

The usage of the Station Keeping tools by various users' is shown in Table 5.11.

TABLE 5.11: USERS USAGE OF THE STATION KEEPING DESIGN TOOLS

Technology Developers	Project developers	Public & Private Investors
▫ Assess the possible layouts fitting their technology for specific sites ▫ Estimate the CAPEX costs for the Station Keeping systems ▫ Explore potential markets with their technology	▫ Design the Station Keeping systems for specific sites and/or technologies ▫ Provide costs for the project development ▫ Compare various technologies and sites from a Station Keeping perspective ▫ Provide first evidences / results for the environmental and socio-economic impacts	▫ High-level estimation of costs related to specific project for their evaluation ▫ Evaluate environmental and socio-economic impacts on the local communities from the Station Keeping systems ▫ Provide data for risk evaluation

5.7.4 INTERFACES

5.7.4.1 GENERAL TYPES OF DATA TO BE CONSIDERED

Input data for this module is:

- Technology type and description (e.g. wetted-part geometry, mass distribution and inertia matrix)
- Site characteristics
  - Physical characteristics (e.g. bathymetry, soil type
  - Metocean data (tide, wind, wave and current)
- Standard / Safety Factors (SF) to be accounted for

Output data is:

- Design configuration (line/anchor types, mooring layout, foundation type for Tidal, umbilical state)
- Bill of material and associated costs
- Installation parameters
- Input files for third-party software (for detailed engineering design and/or advanced calculation including e.g. dynamical behaviour)

5.7.4.2 SUMMARY OF REQUIREMENTS FROM OTHER DTOCEANPLUS TOOLS

Table 5.12 summarises the potential input data needed by the Station Keeping Module from other tools and modules. Note that not all data will be mandatory at all stages and will also depend on the functionality selection made during the project later tasks (T5.1 and T6.1).

TABLE 5.12: NECESSARY INPUTS DATA FROM OTHER DTOCEANPLUS TOOLS AND MODULES

Tools	Modules	Requirements
Structured Innovation		Characteristics of innovative components to be tested
Stage Gate		Potential additional metrics to be calculated during the design/optimisation process, in addition to classical design standards (e.g. class societies rules and guidelines), if applicable
Deployment	Site characterisation	Metocean, geotechnical and bathymetry data, if not provided directly by the user to the Station Keeping module
	Energy capture	Hydrodynamic loads and/or WEC motions, PTO damping (in case some coupling is provided between the two modules)
	Energy transformation	Tidal or Wave energy Converter types, PTO type / damping
	Energy delivery	Umbilical specification
	Logistics and Marine Operations	Logistic constraints, such as maximum handling capacities, limiting for instance the anchor mass, if some limitation applies to the specific site
Assessment	Performance	n/a
	RAMS	Potential additional metrics to be reached during the design/optimisation process, in addition to classical design standards (e.g. class societies rules and guidelines), if applicable
	Lifetime costs	n/a
	Environmental and social impacts	n/a

5.7.4.3 EXTERNAL INTERFACES

Some interfacing with detailed design Station Keeping software like DeepLines, BV Ariane and Orcaflex is foreseen. The information to be passed are:

- Basic inputs data very similar to what DTOceanPlus needs;
- Additional data linked to the higher fidelity capabilities provided by the software, for instance, non-linearity parameters (quadratic roll damping), detailed 3-D bathymetry, 3-D current profiles, i.e. any data needed to drive the additional level of fidelity of the models.

5.7.5 KEY LIMITATIONS OR EXCLUSIONS

One of the key limitations is that some of the assumptions of the Station Keeping module will limit the accuracy of results, particularly at the earliest stages of technology development. However, the "improvement of model fidelity", see TN2.2 [5], is perhaps not the most important requirement. There will be a balance between the potential gains versus needed resources when increasing the detail and accuracy of a model. There will be strong links with the Energy Capture module for Wave Energy Converter this context, since both modules are dealing with calculation of environmental loads on Wave and Tidal Energy Converter devices. It is to be kept in mind that the solving time need to be kept as low as possible for such design tool, as expressed in the user's needs.

5.8 LOGISTICS AND MARINE OPERATIONS [T5.8]

5.8.1 OUTLINE OF LOGISTICS AND MARINE OPERATIONS PLANNING TOOLS

The aim of the Logistics and Marine Operations Planning tools is to assist the user in the design and planning of all lifecycle operations (installation, maintenance and decommissioning) related with offshore ocean energy systems. For each lifecycle operation of a given ocean energy project, the Logistics and Marine Operations Planning tools will define the underlying logistical requirements in terms of vessel(s) characteristics, labour intensity, equipment and port suitability. As for the maintenance operations, maintenance schedules are to be proposed to the user by taking into consideration the reliability, availability, maintainability and survivability models developed in other DTOceanPlus Design tools (T6.4), as well as user specified maintenance strategy preferences (e.g. number of preventive maintenance operations). The tool will propose a technically and physically feasible solution to the user, that minimises total lifecycle operation costs. In Table 5.13, the Operational and Functional requirements of the Logistics and Marine Operations tools are summarised.

TABLE 5.13: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF THE LOGISTICS AND MARINE OPERATIONS PLANNING TOOLS

	Description
Operational requirements	Provide decision support to the user in the design and planning of all lifecycle operations related with offshore ocean energy systems.
Functional Requirements	1) Define the required logistic infrastructure (e.g. vessels, equipment, port facilities) for each operation stage (e.g. installation, maintenance, decommissioning) of a given project,2) Identify of feasible logistic solutions in respect to infrastructure for each operation stage, 3) Develop long-term maintenance plans at the design stage, based on corrective or predictive maintenance strategies, which integrate the outputs from the RAMS models developed in task T6.4. 4) Develop short-term planning of maintenance operations when failure occurs. 5) Must compute an optimal logistical solution that minimises total logistical costs.

The Logistics and Marine Operations Planning tools will derive their inputs from three different sources: (i) user-specified parameters, (ii) Global DTOceanPlus database, namely maritime infrastructure databases that include extensive information regarding port characteristics, vessels, equipment, as well as their performance capabilities, and (iii) relevant outputs from other DTOceanPlus modules. Six major input categories can be identified:

- **Site characteristics and metocean**: the onsite location, bathymetry, the seabed and the metocean resource data (wave height, wave period, wind speed, current speed, etc.).
- **Devices & sub-system specifications**: specifications of the main components of the devices such as their dimensions and weight as well as the description of the assembly and installation strategy preferred for the device.
- **Array layout**: array configuration such as the number and location of the devices and the interspacing configuration.

- **Electrical infrastructure specifications:** relevant characteristics of the grid connection (e.g. the cable types and lengths, substation requirements, etc...)
- **Moorings & foundations specifications**: relevant specifications of the moorings and foundations (e.g. the dimensions and weights of its components, the spatial configuration, etc...)
- **System RAMS:** all relevant information relevant to the maintenance activities such as monitoring, preventive and corrective actions (e.g. type of operation, date, dimensions and weight of components to be replaced, etc.).

For each lifecycle operation, the Logistics and Marine Operations Planning tools will yield as output an optimised logistics solution with respect to vessels, equipment, ports and as well as a maintenance schedule that fulfils the logistic requirements and minimises total costs. The results of the Logistics and Marine Operations Planning tools may be divided in four categories:

1. **Logistical solutions:** a description of the set of ports, vessels and equipment that have been selected.
2. **Schedule:** an expected schedule of the logistical activities with their estimated durations. Logistical operation schedules will provide the expected downtimes due to maintenance activities and delays in the installation phase, which will have an impact on the energy production and farm availability for power production throughout the lifetime of the project (T6.3).
3. **CAPEX and OPEX contributions:** all the costs estimations related to logistic and maintenance operations are gathered and tagged with "capital expenditures" or "operational expenditures".
4. **Contributions to environmental/social impacts:** logistical outputs/parameters that may have an impact on the environmental/social acceptance of a project (e.g. distance to port) will be provided to the Environmental and Social Acceptance module.

5.8.2 ADDRESSING USER REQUIREMENTS

In the user consultation [6], more than 80% of the potential users judged DTOceanPlus ability to assess the Logistics, Operations and Maintenance as at least very important. This not only reflects the very limited experience in planning and deploying ocean energy projects, but also the fact that lifecycle logistics operations contribute to a significant proportion of the overall capital costs (CAPEX) and operational cost (OPEX) of an offshore project. The identified user relating to the logistics and marine operations are compiled below. A more comprehensive table can be found in TN2.2 [5].

The Logistics and Marine Operations Planning tool should be easy to use. Usability was voted as the most important requirement of DTOceanPlus design suite. Roughly 80% of the users confirmed that they would be likely to use the Deployment and Assessment (D&A) tools. Out of all user types, the D&A tools obtained the lowest number of "not very likely to use" replies by Policy & Regulators users. As part of the D&A design tools, the Logistics and Marine Operations Planning tools are valuable to all users, and must be usable for all stakeholders, with different complexity levels.

Complexity and computation costs should be reduced at early project stages. At the concept stage, the Logistics and Marine Operations Planning tools should be quick to use/ compute with less of a focus on the detail. This is particularly important for Policy & Regulators who are not willing to specify a lot of inputs. For the design phase, higher accuracy at the expense of increased complexity and computation times of the Logistics and Marine Operations Planning tools are acceptable/ expected by users

Tool transparency is very important. The Logistics and Marine Operations Planning tools must be transparent in respect to adopted assumptions during calculations, particularly for high level assessments.

The Logistics and Marine Operations tools should be flexible. The Logistics and Marine Operations Planning tools must be fully compatible and integrated with the other design tools in DTOceanPlus. There should be flexibility of the Logistics and Marine Operations Planning tools to link with other software packages. Outputs of this module may be extracted with the level of detail required by the user, in the most appropriate file formats.

5.8.3 APPLICATION OF THE LOGISTIC AND MARINE OPERATIONS PLANNING TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

The different user types require different levels of tool complexity and detail. Lower levels of tool complexity translate into fewer input requirements, fewer intermediate outputs, as well as lower user tolerance to long computational times. In order to accommodate different levels of complexity, the Logistics and Marine Operations Planning tools must be able to assign adequate default values to intermediate logistic operations (e.g. device installation sequence, vessel type), while still allowing more technical/advanced users to override the default values with their own inputs (e.g. vessel daily rates).

5.8.3.1 USE THROUGHOUT PROJECT LIFECYCLE

Regardless of the user type, and required level of accuracy/detail, the Logistics and Marine Operations Planning tools will be integrated at different stages of the ocean energy project.

Assembly, Installation and O&M phases: Experience from DTOcean showed that the logistics tools were considered the most valuable for the installation and O&M stages. For DTOceanPlus, the Logistics and Marine Operations Planning tools will support the installation primarily by selecting the most appropriate set of vessels, equipment and port facilities to perform the following operations:

- Trenching, laying and protecting the electrical cables,
- Installing the other electrical infrastructure equipment and substation when necessary,
- Positioning and pre-installing the moorings and foundations,
- Transferring and assembling all components of the devices from the port to the site,
- Installing, positioning and connecting the devices to the electrical infrastructure and the moorings and foundations hardware equipment.

Moreover, the Logistics and Marine Operations Planning tools will further improve maintenance operations by developing optimal maintenance schedules that minimise costs while respecting the component maintainability/reliability requirements.

Manufacturing: Since the manufacturing and assembly requirements are closely associated, the Logistics and Marine Operations Planning tools will attempt to consider manufacturing requirements when necessary. These will be achieved by considering the port manufacturing capabilities, the storage capacity, lifting and manoeuvring equipment to cover eventual manufacturing and the assembly requirements.

Decommissioning: At the current stage of development of the ocean energy sector, forecasting the logistical requirements for the decommissioning stage of ocean energy farms is not trivial, mostly because, no commercial arrays have yet been decommissioned. Still, the Logistics and Marine Operations Planning tools will support the decommissioning stage, by importing the common procedures of the offshore wind industry.

5.8.3.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

The Logistics and Marine Operation Planning tool complexity will be intrinsically related to the level of assessment (high-level or low-level) and stage of the project lifecycle (concept definition, feasibility and design & deployment stage). The absolute minimum user input requirements will have to be firstly defined. For the remaining inputs, default values will be obtained using a lookup table when applicable. This is the case of metocean data which, if not specified by the user, can be replaced with rough estimations from open-access online databases. Conversely, in some cases, using default values may be counterproductive and simplified functions might be defined instead. An example may be the estimation of the total port costs.

5.8.3.3 USE IN STRUCTURED INNOVATION AND STAGE GATE DESIGN TOOLS

The Logistics and Marine Operations Planning tools have the potential to provide valuable insights regarding the future logistic requirements associated with a given technology or project even at their early development stages. The Logistics and Marine Operations Planning tools may unveil, even at an early development stage, some unexpectedly expensive logistics requirements and operations that may be associated with a given concept, as well as cost reduction pathways that may be achieved with simple concept adjustments.

For instance, the dimensions of a given device or sub-system may require an assembling strategy that renders impossible the use of widely available and low-cost logistic infrastructures (vessels, ports). This may lead to unexpectedly high logistics and operation costs, and subsequently increased project Levelised Cost of Energy (LCOE). The ability to retro-fit logistic requirements and widely available logistical infrastructures in the Structured Innovation design tool might be leveraged to identify promising cost-reduction opportunities. Additionally, logistics and marine operations planning has the potential to contribute to the risk assessment.

5.8.3.4 APPLICATION TO SUB-SYSTEMS, DEVICES, AND ARRAYS

The Logistic and Marine Operation Planning tools will be applicable to arrays, while considering main sub-systems. Sub-systems such as offshore substations will be analysed to define the associated installation and maintenance operations logistical requirements, as well as how these sub-systems are integrated in the array deployment operation.

5.8.3.5 USE BY DIFFERENT USER ROLES

The different user types will have different needs and require different levels of tool complexity and detail. The different uses may be summarised in Table 5.14.

TABLE 5.14: LOGISTICS AND MAINTENANCE OPERATION PLANNING TOOLS USES BY DIFFERENT USER ROLES

Technology Developers	Project developers	Public & Private Investors
▫ Assess the available logistics infrastructures that can be used for their technology, ▫ High-level estimation of the CAPEX and OPEX contributions to the total costs of the technology, ▫ High-level assessment of the logistic impacts on energy production.	▫ Define in detail the logistics requirements of a given project, ▫ Schedule in detail the logistical activities with their estimated durations, ▫ Estimate in detail the costs associated with the required logistics and maintenance operations, ▫ Estimate the impact of the logistics and operations on the energy production throughout the lifetime of the project, ▫ Assess the risks associated with the logistics and operations, ▫ Assess the environmental impacts that are associated with a given logistics and maintenance solution.	▫ High-level estimation of the logistics and maintenance contribution to total project LCOE, ▫ High-level assessment of the logistics and maintenance operations contribution to the total environmental impacts, ▫ High-level assessment of the contribution of the logistics and maintenance operations to the total project risks.

5.8.4 INTERFACES

5.8.4.1 GENERAL TYPES OF DATA TO BE CONSIDERED

The Logistics and Marine Operations Planning tools will require several inputs to produce meaningful logistics solutions and operation plans. Regardless of the origin and level of detail, the minimum expected input variables are:

- Project start date
- Site characteristics: location, bathymetry, soil type.
- Metocean data, as time series.
- Device characteristics: device technology, number of units and dimensions
- Sub-system components and characteristics: type, number, dimensions.
- Moorings and Foundations specifications: type, dimensions.
- Export and umbilical cables specifications: number, type, length, cable laying strategy
- Assembling, load out, transportation, and landfall methods and specifications.
- Reliability information and maintenance requirements

However, at a concept stage, some of these inputs may not be required to be introduced by the user. At an early stage, rough estimates of the site characteristics, such as bathymetry, might be obtained from other sources, such as open source databases. This will lead to less accurate but still transparent results, at a lower computational effort.

5.8.4.2 REQUIREMENTS FOR OTHER DTOCEANPLUS TOOLS

The Logistics and Marine Operations Planning tools will use the output of several other tools developed within DTOceanPlus design tool suite:

- **Site characteristics and metocean:** Data related to site and local environment will be derived from user inputs and from the Site Characterisation module
- **Devices & sub-systems specifications:** Inputs will be obtained from the Structured Innovation tools, Stage Gate design tools as well as user specifications.
- **Array layout:** Data related to the array layout will be derived from the Energy Capture module.
- **Electrical infrastructure specifications:** Inputs related to substation characteristics, cable routing, cable specifications and requirements will be derived from the Energy Delivery module.
- **Moorings & foundations specifications:** Data related to the foundations and moorings will be derived from the Station Keeping tool.
- **System RAMS:** Data related to the devices and sub-systems maintenance requirements will be derived from the System RAMS module.
- **System Lifetime Costs:** Economic assessment of the logistic solutions should be carried out in collaboration with the System Lifetime Costs assessment tool.

5.8.4.3 EXTERNAL INTERFACES

Site environmental characteristics and metocean historical data are fundamental inputs for the Logistics and Marine Operation Planning. It is very likely that less technical users such as Policy & Regulators might not have access to – or be willing to introduce – long time series of metocean data. For this purpose, it could be advantageous to integrate metocean databases, which could provide rough but good enough estimates for preliminary logistics and operation planning.

5.8.5 KEY LIMITATIONS OR EXCLUSIONS

The Logistics and Marine Operations Planning tools is a comprehensive tool but with limitations that fall out of the DTOceanPlus project scope:

- The Logistics and Marine Operations Planning tools will not be designed for real time management. For simplicity purposes, average locations, costs and vessel availability values will be considered instead of implementing a vessel live tracking system and quotes for individual vessels that greatly complicate the tool.
- Seasonal cost variations (vessel daily rates etc.) as well as other factors will be incorporated in the tools where possible.
- Landfall preparation works that are related to onshore operations and performed independently of other logistic works will not be assessed in detail.
- A detailed cable burial risk assessment will not be performed.

6. ASSESSMENT DESIGN TOOLS

6.1 INTRODUCTION AND CURRENT STATE-OF-THE-ART

The **Assessment Design tools** will provide a dual role: firstly to provide objective information to the developer or investor on the suitability of a technology and project; and secondly to support the other DTOceanPlus design tools. Again, these tools will improve and expand on the capabilities of the original DTOcean software, split into four modules as presented in table 6.1.

As discussed in section 1.3, the original DTOcean software is also considered as state-of-the-art in terms of assessment tools for ocean energy. This integrated open-source software has the ability to provide optimal solutions for array design for wave and tidal energy deployments. DTOceanPlus will build on this functionality, incorporating user requirements identified in the consultation exercise.

The functional requirements produced for the assessment design tools to be developed in work package 6 are listed in the subsequent sections, starting with general requirements.

TABLE 6.1: ASSESSMENT DESIGN TOOLS DEVELOPED IN WP6

Name	Task	Compared to DTOcean
System Performance and Energy Yield	T6.3	Improved functionality
System Lifetime Costs	T6.4	Improved functionality
System Reliability, Availability, Maintainability, Survivability	T6.5	Expanded scope
Environmental and Social Acceptance	T6.6	Expanded scope

6.2 GENERAL REQUIREMENTS FOR THE ASSESMENT DESIGN TOOLS

The general requirements for the Deployment and Assessment design tools are covered in section 5.2, as there is significant commonality between them.

As previously noted, in addition to performing standalone analysis of devices and projects, the Assessment design tools provide a role to support the other design tools within the DTOceanPlus suite, particularly the Stage Gate and Structured Innovation design tools.

A toolset will be developed to globally assess the design of each technology (sub-system, device, or array). This is a complex but key part of the overall tool which will provide information to the developer on the suitability of a technology for commercial development, using technical and non-technical analysis to provide key metrics. The final target of the toolset is to empower the developers to correctly target their efforts to technology designs that have the required metric achievement, and produce data for potential investors to evaluate the technologies. The toolset will use a number of methods (including models, decision making processes, and benchmarking) to evaluate criteria such as: performance, reliability, availability, maintainability, survivability, lifetime costs, plus environmental and social acceptance.

6.3 SYSTEM PERFORMANCE AND ENERGY YIELD [T6.3]

6.3.1 OUTLINE OF SYSTEM PERFORMANCE AND ENERGY YIELD TOOLS

These tools will provide information to the user on the performance level of each subsystem, device or array. For this issue, the tool will compute the evaluation metrics and will consistently benchmark a technology against a set of technologies, supporting the Stage Gate design tools.

TABLE 6.2: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF THE SYSTEM PERFORMANCE AND ENERGY YIELD TOOLS

	Description
Operational requirements	Provide information about the system performance and energy yield in order to evaluate and compare different subsystems, device or array.
Functional Requirements	1. Estimate power production per sub-system, device and array 2. Estimate losses of different elements 3. Compute evaluation metrics to compare different technologies

6.3.2 ADDRESSING USER REQUIREMENTS

With the objective that the tools meet the expectations of future users, Deliverable D2.1 "Results from user-groups consultation" has been deeply analysed in depth.

In summary, the results from the user consultation show that users expect to obtain results from all the tools in DTOceanPlus (Stage Gate design tool, Structured Innovation design tool, Deployment and Assessment design tools) at different **levels of aggregations**. The outputs required by users differs depending on the role that they have (**Public funders, Innovators and developers, project developers and utilities, Policy makers and regulators**).

The main requirements from the users are summarised below:

- In general terms, users give priority to computation of energy capture at array level.
- Users are interested in a project life analysis, and give more importance to Levelised Cost of Energy (LCOE) minimisation than Annual Energy Production (AEP) maximisation.
- The users would like to be able to compare different sites, and identify pathways for cost reduction.
- Assessment tools should support also stage gate tools to guide investors by analysing reliability, survivability, giving evaluation standardised metrics.
- According to concept developers' responses they are not going to use the tools for concept optimisation, they are going to use the tool for a global farm evaluation.
- Users would like to have information that helps identifying and quantifying challenges, identifying enabling technologies and generating ideas to optimise a device /array.
- The process to obtain the results must be well explained and based on previous work with the objective to help standardisation.

6.3.3 APPLICATION OF THE SYSTEM PERFORMANCE AND ENERGY YIELD TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

The tool will provide outputs at different levels of aggregation, e.g. outputs at subsystem level as well as global outputs. The user should analyse the results and use them correctly depending on the detail level of the inputs.

6.3.3.1 USE THROUGHOUT PROJECT LIFECYCLE

The System Performance and Energy Yield tools will consider the phase of the project lifecycle (early stage, mid stage or late stage), as these tools will support the decisions of the Stage Gate and Structured Innovation design tools at early and mid-stage and will assess the power production and system performance at late stage of design.

6.3.3.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

As mentioned in 6.3.5, the treatment of uncertainty and incomplete data within the System Performance and Energy Yields tool will depend essentially on the uncertainty of input data as well as the accuracy of model used in the deployment tools. In case of incomplete data, depending on the specific missing variables, then some default values could be used; if not possible, then an incomplete outcome is expected.

6.3.3.3 SUB-SYSTEMS, DEVICES, AND ARRAYS

The tool will provide answers and solutions at any aggregation level, providing information about efficiency, power production and losses at array level, as well as device and sub-systems when applicable.

6.3.4 INTERFACES

The different subsystems of the model are interconnected, outputs from structured innovation tool and deployment tools are inputs for assessment tools and outputs from assessment tool are inputs for stage gate.

6.3.4.1 GENERAL TYPES OF DATA TO BE CONSIDERED

The system performance and energy yield will require as input data, in general, power generated by the hydrodynamic systems, and the efficiency of the sub-systems through the different steps of the conversion, from the PTO, to the power transmission system, accounting for the availability of the site. The minimum expected variables which will be used are:

- **Energy in a site**: Through scatter diagrams, time series, or consistently to the inputs in the Energy Capture module.
- **Capture efficiency/capture width**: This input should be consistent with the outcome of the Energy Capture module.

- **Availability**: Considering the characteristics of the PTO and the weather climate, this input could be expressed as constant factor, or as a coefficient for each element of the scatter diagram (in case of wave energy converters).
- **Efficiency of transformation**: It could be assumed to be constant for all the sea states, or a value for each sea state/tidal condition.
- **Efficiency of transmission**: It could be assumed to be constant for all the sea states, or a value for each sea state.
- As an output, the **Annual Energy Production** (AEP) is expected, for different level of aggregations. Other outputs could be expressed if a need from the users is identified, such as relative power production in terms of percentages of the maximum power extractable, or seasonal outputs if possible.

6.3.4.2 REQUIREMENTS FOR OTHER DTOCEANPLUS TOOLS

The "System Performance and Energy Yield" tool will interact with the following deployment tools:

- **The Site Characterisation module**, to get information about the resource.
- **The Energy Capture module**, to receive inputs about the hydrodynamic efficiency of the device and of the array.
- **The Energy Transformation tool**, to receive inputs about the efficiency of the PTO, the control strategy.
- **The Power Transmission tool**, to receive inputs in terms of the efficiency of transmission system.
- **The Logistics and Marine Operation Planning**, to receive information about the downtime and availability of the plant.

Similarly, the System performance and energy yield tool will interact the following assessment tools:

- **The RAMS tool**, in order that the information about the availability of the plant is consistent throughout all the tools.
- **The System Lifetime Costs tool**, as the energy production will affect the cost of the energy and incomes derived by the production of energy.
- **The System Environmental and Social Acceptance tool**, for analysing how the impact of the reduction of energy in the resource will affect the environment.

Moreover, this tool will interact tightly with the Stage Gate design tool, in order to compute the metrics to be used to facilitate the stage gate decision making at different TRLs.

In order to have the System Performance and Energy Yield tool working properly, data format consistency is required across the suite of tools.

6.3.4.3 INTERFACING WITH OTHER EXTERNAL TOOLS/SOFTWARE PACKAGES

Essentially, the tool with work with the input variables provided by other tools (see 6.3.4.1 and 6.3.4.2). Thus, in case the user wants to connect the System Performance and Energy Yield tools with other available software, then he or she should be able to do this as long as the import/export data formats are consistent.

6.3.5 KEY LIMITATIONS OR EXCLUSIONS

The major limitation of these tools is the accuracy of the outcome. Indeed, as most of the assessment tools, they will hinge upon the accuracy in the input data and the models used in the deployment tools.

6.4 SYSTEM RAMS [T6.4]

6.4.1 OUTLINE OF RAMS TOOLS

The Reliability, Availability, Maintainability and Survivability (RAMS) tools support the user to assess the reliability of a technology, at sub-system, device or array level and, together with the Logistic and Marine Operation Planning module, will identify the operational cost of the project. These will be built upon state-of-the-art RAMS tools for Ocean Energy or from other more mature sectors. The Operational and Functional requirements of the RAMS tool are presented in Table 6.3.

TABLE 6.3: OPERATIONAL AND FUNCTIONAL REQUIREMENTS FOR THE RAMS TOOLS

	Description
Operational Requirements	Estimation of the reliability, availability, survivability and maintainability of sub-systems, devices or arrays of ocean energy technologies
Functional Requirements	1. Assess reliability of mechanical / electrical /control components and systems using classical reliability methods based on component failure rates 2. Assess reliability and survivability of structural components (incl. mooring lines and e.g. load bearing welded steel beams) using structural reliability methods based on formulation of limit state equations and stochastic models for uncertain parameters 3. Provide required data to support assessment of availability, maintenance planning and repair costs by other tools (Logistics and Marine Operations Planning & System Lifetime Cost)

6.4.2 ADDRESSING USER REQUIREMENTS

Several user needs for the RAMS tool have been identified through the user consultation. Although most of the user requirements are general for the Deployment and Assessment tools, two specific comments have been given to the RAMS, which will be considered during the project period:

"... Reliability is also a difficult metric to calculate/estimate for devices at the concept stage. They thought it important to show research on how the metrics used at an early stage link to the commercial stage, and justify the metrics used in DTOceanPlus with citations of other research."

"It would be very nice to assess reliability and availability as early as possible; however, it is very difficult to do this before a significant amount of operation hours have been accumulated by a given technology."

The main requirements are summarised below:

(i) The most likely stages in which the tool is to be used are in concept selection and feasibility studies

(ii) Even though accuracy is very appreciated, the phase requiring most accuracy is the design stage. Additionally, the user is expecting to spend from some hours to a few days building the model and they are going to do themselves rather than sub-contracting.

(iii) Deployment and assessment tools are very well understood so far and very likely to be used by a broad range of user types, from 'policy makers and regulators' to project developers

(iv) Usability is appreciated together with modularity

The tool is expected to be reasonably accurate at early phases of the project lifecycle. Identified user needs point at focusing the efforts of RAMS tools at the concept and feasibility studies (i). The level of detail required should be enough to provide statistical properties of the power transformation with mid-to-low uncertainty level (ii).

The tool should be easy to use (iv). Deployment and assessment set of tools is better understood than other sets of tools; the inclusion if this module should be kept simple (iii). Not requiring very detailed information is aligned with the requirement of spending some hours to a few days for inputting data (ii).

6.4.3 APPLICATION OF RAMS TOOLS AT DIFFERENT LEVEL OF COMPLEXITY

6.4.3.1 USE THROUGHOUT PROJECT LIFECYCLE

The RAMS tools will assess the reliability, availability, maintainability and survivability at all stages of the project lifecycle, these are:

- At early stage, high-level calculations for RAMS based on fundamental physics, engineering and economics relationships. There would be a link here to the Structured Innovation design tool in the high-level assessment of concepts.
- When more data is available, the assessment would be based on the 'basic' mode of the RAMS tools with the optional use of simple parameters and/or default values for some of the key variables which are missing.
- When all required data is available then the tool can operate in 'advanced' mode for the highest detail (lowest uncertainty) assessment.

The above classification will be reflected directly in the time requirement both for input formatting and calculation.

6.4.3.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

When data is incomplete, it is still important to be able to assess reliability, availability, maintainability and survivability of concepts at this early stage. These assessments will be developed as high-level calculations for RAMS based on fundamental physics, engineering and economics relationships (integrated with the Structured Innovation design tool in the high-level assessment of concepts)

When more data is available, the assessment would be based on the 'basic' mode of the RAMS tools with the optional use of simple parameters and/or default values for some of the key variables which are missing.

6.4.3.3 USE IN STRUCTURED INNOVATION AND STAGE GATE DESIGN TOOLS

The RAMS tools can be used in both Structured Innovation and Stage Gate design tools to estimate technology potential and to compare different technology types. Reliability and fatigue have been highlighted as particularly important variables in the stage gate process.

6.4.3.4 APPLICATION TO SUB-SYSTEMS, DEVICES, AND ARRAY

The RAMS tools can be used to assess the probability of failure and failure rates for electrical, mechanical and control components. These metrics will be defined for the single sub-systems, as well as for the devices and array.

On the other ends, the survivability will be assessed only at "critical" structural components, such as mooring or PTO connections, or similar specific items, because their capability to withstand fatigue and extreme loads is crucial for the overall failure of the aggregated systems.

6.4.3.5 USE BY DIFFERENT USER ROLES

The main expected users will be developers or designers who need to estimate the lifetime OPEX costs, including operation & maintenance costs, but the tool will be usable by all the user classes including public and private funders.

6.4.4 INTERFACES

6.4.4.1 GENERAL TYPES OF DATA TO BE CONSIDERED

For the two major groups of components, the RAMS tool requires the following inputs:

- Electrical / mechanical / control components
  - Input from FMEA analysis (link to the Structured Innovation design tool) characterising the system in terms of dependencies (hierarchy and redundancy) of components, i.e. this requires identification of critical failure modes and the components in such failure modes. For this group of systems/sub-systems annual failure rates of the components are needed.
- Structural components
  - For structural components, it is assumed that a limit state equation is formulated as a function of a number of parameters modelled by stochastic variables. This is done for the following design load cases (DLC) for both (a) fatigue failure and (b) extreme load: DLC 1) Normal operation; DLC 2) Normal operation with fault in electrical / mechanical / control system; DLC 3) parked position where relevant, see also DSF/IEC/TS 62600-2 Ed. 1.0. For this group of components, stochastic models are needed for uncertain parameters and simulated time series of load effects are needed for the three design load cases for given wave and wind conditions.

6.4.4.2 REQUIREMENTS FOR OTHER DTOCEANPLUS TOOLS

- Perform a FMEA analysis (link to the Structured Innovation design tool) to identify critical failure modes for the electrical / mechanical / control system (which can be linked to the operation & maintenance cost consequences using the output from the RAMS tool with information on weather conditions), and to identify failure modes which can result in larger load effects in the structural components in DLC 2 above.
- Time series of load effects in DLC 1, DLC 2 and DLC 3 above.

6.4.4.3 EXTERNAL INTERFACES

The RAMS tool will import/export via common data formats with standard reliability analysis software (for classical reliability analysis and for structural reliability analysis) where relevant.

6.4.5 KEY LIMITATIONS OR EXCLUSIONS

No specific limitations or exclusions are foreseen for the RAMS tools at this stage, but this will be developed further in T6.1.

6.5 SYSTEM LIFETIME COSTS [T6.5]

6.5.1 OUTLINE OF SYSTEM LIFETIME COSTS TOOLS

The set of System Lifetime Costs tools will determine the costs of the sub-systems, devices or arrays throughout the lifetime of a project, and ultimately its economic and financial viability. This will include:

i) Costing of components, through either typical costs or cost estimating;
ii) Aggregation of costs into common metrics such as CAPEX and OPEX;
iii) Calculation of discounted lifetime costs and of the Levelised Cost of Energy (LCOE);
iv) Calculation of financial viability metrics, such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Time.

In Table 6.4, the Operational and Functional requirements of the System Lifetime Costs tools are summarised

TABLE 6.4: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF SYSTEM LIFETIME COSTS TOOLS

	Description
Operational requirements	Provide a detailed assessment of the lifetime costs of a system or project, revealing its economic and financial viability.
Functional Requirements	1) Estimate lifetime costs based on environmental conditions, such as associated fatigue and operations/maintenance costs 2) Evaluate economic and financial viability 3) Identify cost-reduction pathways 4) Provide investors with the information they need to identify promising technologies and remaining challenges that need to be overcome through further funding and investment. 5) Include assessment of financing of pre-commercial projects.

The System Lifetime Cost tools derive their inputs from two different sources: (i) user inputs and (ii) outputs from other DTOceanPlus modules. The inputs can be categorised as:

- **Bill of materials:** System/device/project description in terms of a bill of materials should be specified to perform the costing analysis, where available. At the lowest TRL levels, simpler parameters and assumptions will be made to account for any missing data. Where possible, data will be supplied by several modules, namely Energy Transformation (T5.5) for the PTO components, Energy Delivery (T5.6) for the Electrical sub-systems, Station Keeping (T5.7) for the moorings/foundations components.
- **Energy production data (T5.5):** Data on the energy production is required to estimate the LCOE and assess the economic viability.
- **Project developers' parameters:** Parameters such as the discount rate and project lifetime must be introduced by the user for project appraisal. The project lifetime will have been defined for the operations and maintenance analysis (T5.8 Logistics and T6.4 RAMS). For financial viability analysis, these will need to be provided by the user.

As outputs, the System Lifetime Cost tools will yield the Total Lifetime Costs, LCOE, IRR, NPV and Payback Time.

In Figure 6.1, a schematic representation of the System Lifetime Costs tool is presented. It can be observed that the economic and financial viability functions require outputs from the costing functions.

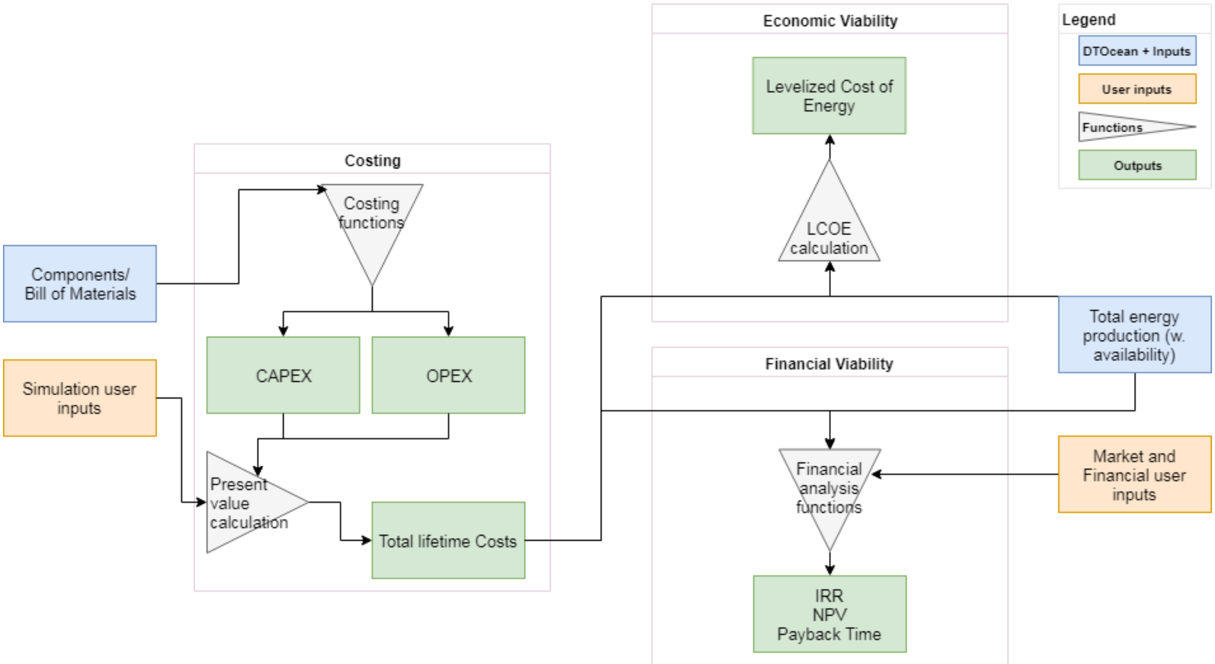

FIGURE 6.1 SCHEMATIC REPRESENTATION OF THE SYSTEM LIFETIME COST TOOLS

6.5.2 ADDRESSING USER REQUIREMENTS

From the user consultation, the main user needs in terms of lifetime costs analysis relate to:

1. Minimising Levelised Cost of Energy (LCOE) instead of maximising Annual Energy Production (AEP).
2. Estimation of lifetime costs based on environmental conditions (associated fatigue and operations/maintenance costs).
3. Identification of cost reduction pathways.
4. Present investors with the information they need to identify promising technologies and remaining challenges that need to be overcome through further funding and investment.
5. Inclusion of financing of pre-commercial projects.

Relating to the first of these user needs, the initial intent of the first set of DTOcean tools was to minimise the LCOE, although each module would minimise cost as a first step. DTOceanPlus will assess the LCOE for a set of design choices from the different upstream modules.

The estimation of lifetime costs based on environmental conditions can be achieved by the articulation between the RAMS, Logistics and Marine Operation Planning and the System Lifetime Cost tools, which is the planned core functionality of these tools. However, this will require detailed information on the technology operation, and may only be suitable for late stage analysis.

Benchmarking functions and data can be used to identify cost reduction pathways, promising technologies and the remaining challenges, in conjunction with the Structured Innovation and Stage Gate design tools.

For the financial viability analysis, further than the simple calculation of the NPV and IRR, the tool can present the user with different financing combinations that allow the feasibility of the project, in terms of capital grants, feed in tariffs and debt financing.

6.5.3 APPLICATION OF SYSTEM LIFETIME COSTS TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

6.5.3.1 USE THROUGHOUT PROJECT LIFECYCLE

In order to calculate the full detail of LCOE and system lifetime costs, the costing functions require that all project items are known, and can be described either in terms of a specific component model or a typical component. As the estimation of the system lifetime costs are a prerequisite for the economic and financial viability analysis, a complete bill of materials is desired but may not be available at the earliest TRL levels.

For low TRL and/or high-level device analysis, other economic metrics will be developed, an example of one of these could be the ACE[3] metric developed for the U.S. Energy Department's Wave Energy Prize, can be used to provide an estimation of the economic viability of the concept.

The Structured Innovation design tool will require high level lifetime cost assessments to measure the attractiveness of concepts which are generated, and the Stage Gate design tool will require lifetime cost assessments at all stages of technology development. These will increase in detail and decrease in uncertainty as more data, such as the bill of materials and energy yield data become available.

Therefore, the assessment of the different costs can be used at any stage of the project lifecycle, but a full detailed assessment of the LCOE and financial viability metrics require information on the entire project costs.

[3] Metric obtained from dividing the Average Climate Capture Width (ACCW, a measure of the effectiveness of a WEC at absorbing power from the incident wave energy field) by the Characteristic Capital Expenditure (CCE, a measure of the capital expenditure in commercial production of the load bearing device structure).

6.5.3.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

At all stages of the project lifecycle, lifetime costs will be assessed. In the case of incomplete data then lifetime costs will be made by either:

- Using fundamental physics, engineering and economic relationships which will be developed alongside the Structured Innovation and Stage Gate design tools.
- Simple, high level quantitative assessments – this may be a simplified version of the Lifetime Costs tool; in 'basic' mode. These assessments may be derived from typical values from literature.
- The use of the full detailed 'advanced' tool with some default values

Typical values for cost centres (at component, sub-system, device, or array level) should be available to use as default in case there is data missing. However, the results should explicitly mention that lower reliability data has been used.

For the financial analysis, if the data has a high degree of uncertainty, the tool should advise the user not to run it.

6.5.3.3 USE IN STRUCTURED INNOVATION AND STAGE GATE DESIGN TOOLS

Both the Structured Innovation and the Stage Gate design tools will require lifetime cost assessments.

As described above in 6.5.3.2, at the earliest TRL stage when little quantitative data is available, the lifetime cost assessment will work alongside the Structured Innovation and Stage Gate Design Tools in order to create, assess, and select concepts using either fundamental physics, engineering and economics relationships, 'basic' mode of the lifetime costs tool, or the full detailed 'advanced' quantitative assessment with use of default values.

6.5.3.4 APPLICATION TO SUB-SYSTEMS, DEVICES, AND ARRAYS

The costing functions of this tool can be applied at any assessment level. Ideally, the costing can be made at component level, with aggregation into sub-system, device, and array. The economic and financial assessment functions, however, are only applicable at project (array) level.

6.5.3.5 USE BY DIFFERENT USER ROLES

The different user types will have different needs and require different levels of tool complexity and detail. The different uses may be summarised in Table 6.5.

TABLE 6.5: SYSTEM LIFETIME COSTS TOOLS USES BY DIFFERENT USER ROLES

Functions	Technology Developers	Project developers	Public & Private Investors
Costing functions	Assess the CAPEX and OPEX of the technology	Determine the total costs associated with the project	Assess the total costs associated with the project
Economic feasibility	Assess the LCOE of a typical array project	Determine the LCOE of a specific array project	Determine the LCOE of a specific array project and how it compares with others
Financial feasibility	Demonstrate economic and/or financial feasibility to attract investment and support	Demonstrate economic and/or financial feasibility to attract investment and support Determine required financing needs of the project	Demonstrate financial feasibility of a project, based on specific financial inputs.

6.5.4 INTERFACES

6.5.4.1 GENERAL TYPES OF DATA TO BE CONSIDERED

For components, costs should ideally be provided by suppliers and manufacturers, meaning that the cost data would need to be stored according to the following template:

- Component ID
- Cost value:
- Cost currency
- Year of quote
- Reference

In the absence of quoted data, the costs of components can be estimated through functions based on experience, which would be related to design specifications, unit price of materials and the geometry of the design.

For the economic analysis, the data needed would include:

- Bill of materials, aggregating all the cost values and when these occur in the lifetime of the project
- Annual Energy Production, either an average number for year, or a specific value for each year and/or device
- Project lifetime
- Discount Rate

For the financial analysis, the following data is needed:

- Project lifetime
- Capital Grant(s) amount
- Support Scheme Type
- Support Scheme Value
- Duration of special electricity tariff
- Electricity market price
- Return to equity, if divided by multiple investors, the share of each would also be requires
- Debt fraction, the percentage of the CAPEX that is financed through debt.

- Debt interest rate
- Debt term

6.5.4.2 REQUIREMENTS FOR OTHER DTOCEANPLUS TOOLS

A bill of materials is required for this module to run in full complexity and detail. The bill of materials is an aggregation of all components that will be present at the project, also detailing when in the project lifetime these costs are incurred. This means that there are data requirements from all modules developed in work package 5 (Deployment Design tools). For early stage assessments, the bill of materials may not be fully specified to component level, but only include major sub-assemblies with costs estimated in the fundamental and basic mode.

For the calculation of the LCOE, the annual energy production is also required, meaning that data from work package 6 (Assessment design tools) is required, namely the energy yield and availability.

6.5.4.3 EXTERNAL INTERFACES

It should be possible for the user to save the detailed cashflow analysis and bill of materials, at least in a text format (csv), in order to be able to combine the results from DTOceanPlus with in-house analysis.

Cost data input from third party tools may be possible following depending on the format of exports, but a container for .csv import could be implemented.

6.5.5 KEY LIMITATIONS OR EXCLUSIONS

As tax schemes will differ from country to country the financial analysis within the tool will be always preformed before taxes.

6.6 ENVIRONMENTAL AND SOCIAL ACCEPTANCE [T6.6]

6.6.1 OUTLINE OF ENVIRONMENTAL AND SOCIAL ACCEPTANCE TOOLS

The environmental and social acceptance module aims to assess the environmental and social impacts generated by the various technology choices and array configurations of wave or tidal devices. For each lifecycle operation of a given ocean energy project, the environmental and social acceptance module will assess the potential environmental and social impacts of the project in terms of pressure existence (e.g. chemical pollution or collision risk with marine fauna), receptor sensitivity (e.g. functioning of local marine ecosystems) and social acceptance (e.g. carbon footprint of the project or economic benefits). At the end of the simulation, recommendations to reduce the potential environmental impacts and to increase social acceptance during the total lifecycle of a project is proposed to the user. In Table 6.6, the Operational and Functional requirements of environmental and social acceptance module are summarised.

TABLE 6.6: OPERATIONAL AND FUNCTIONAL REQUIREMENTS OF THE ENVIRONMENTAL AND SOCIAL ACCEPTANCE TOOLS

	Description
Operational requirements	Provide environmental and social impact assessment to the user during all lifecycle operations related with offshore ocean energy systems.
Functional Requirements	1) Characterise the sensitivity of receptors, leading to enhanced environmental impact assessment of the state of the marine ecosystem before and after energy arrays deployment, improving DTOcean environmental functions 2) Evaluate environmental indicators which capture the sensitivity of receptors, using existing databases. The purpose here is to produce an initial environmental state assessment for the ecosystems where devices are to be deployed. 3) Introduce the social impact assessment tool: i) Evaluate the political assessment process, using the latest information of the applicable frameworks. ii) Evaluate the socio-economic impact (e.g. in terms of job creation and growth). Those two social impacts will be introduced for the first time in a design tool. 4) Store a georeferenced environmental database of species and local impacts, using Geographical Information Systems (GIS), that will facilitate the usage and improve accuracy of the environmental impact assessment. Other links to WP5 tools will be introduced to allow estimating impacts based on the technology.

The Environmental and Social acceptance tools can be divided into environmental functions and social acceptance functions. The environmental functions will be built on, and expand the capabilities of, the environmental functions that were developed for the original DTOcean project, while the social acceptance functions will be implemented for the first time.

Similar to DTOcean, the environmental impact assessment will be performed by a collection of specific functions that evaluate the potential pressures generated by the device array on the maritime environment. These functions are, for instance, dedicated to footprint, noise or risk collision. Each environmental function links two entities: (a) the 'stressors', i.e. the entities that generate a pressure or an environmental effect and (b) the 'receptors', the entities that are potentially sensitive to stressors. A stressor is any physical, chemical, or biological entity that can induce a response. Stressors may adversely affect specific physical resources of marine ecosystems that interact directly with the biological components of these ecosystems, including plants and animals.

Through a 3-step process considering the quantification of the 'pressure' generated by the stressors, the quantification of the receptor sensitivity and qualification of the seasonal distribution of receptors, a score of environmental data is obtained. Quantitative and qualitative outputs can be derived from the process:

- An overall score of impact (from +50 to -100)
- An impact score by modules
- Recommendations of technologies to increase impact score

In DTOceanPlus, the focus will be on the receptors' sensitivity by investigating changes in species biodiversity and more generally, changes occurring in the structure and the functioning of marine ecosystems where ocean energy devices are deployed. This will enhance the environmental impact assessment, allowing the production of an initial environmental assessment prior to the devices deployment. The initial environmental assessment will be based on a series of indicators (i.e. new functions in DTOceanPlus), such as biodiversity indices or abundance evolution of selected species, to capture the environmental status. The environmental impact assessment after deployment of devices can be achieved based on modelling projections.

Beyond the environmental impact assessment, the social acceptance of an offshore ocean energy system is also a key parameter to consider when implementing a new project. The social impact of energy device development and deployment can have positive impacts on local communities and limited perturbations to local activities. For instance, the offshore ocean energy system will produce green energy which can be related to a reduced carbon footprint. The installation of these systems will also produce a new local industry which will be translated by the creation of new employment opportunities and reinforcement of local companies who will be mobilised for the array device development.

The Environmental and Social Acceptance tools will derive their inputs from two different sources. Some data will have to be provided by the user (manually or from database), other data will come directly from the other modules.

6.6.2 ADDRESSING USER REQUIREMENTS

The DTOcean first workshop feedback [55] has shown a positive opinion of the environmental functionality and of the methodology which has been seen as transparent. A large majority of respondents viewed recommendations to mitigate environmental impacts as useful and quantifying positive environmental impacts was strongly supported as this can potentially enhance the political and social acceptance of ocean energy projects.

In DTOceanPlus, the importance of assessing environmental and social aspects was ranked relatively lower in the user consultation. In follow up discussions (Table 6.7), the reasons given for this included a number of factors that are listed below:

TABLE 6.7: SUMMARY OF THE KEY USER REQUIREMENTS FOR ENVIRONMENTAL & SOCIAL ACCEPTANCE TOOLS IN DTOCEANPLUS

List of factors	Implementation in DTOceanPlus
"DTOcean environmental assessment module is currently based in scores for different affected areas. Another approach I would like to see is the environmental impacts focused on CO_2 emissions (based on my experience that would be a more industry based approach)".	The focus on carbon emissions is very relevant in the context of renewable energy deployment. A function will be added to DTOceanPlus which deals with the carbon footprint. The idea is to propose a quantitative estimation of carbon footprint of the deployed energy device, considering all its life cycle stages, from conception to decommissioning.
"Environmental and social issues are very location dependent, and may be difficult to quantify easily enough to use within a tool. For social issues particularly, these may be better dealt face-to-face, as they can be hard to quantify if not engaged directly with that community."	What is proposed in DTOceanPlus is a quantification of the environmental and social impacts of ocean energy deployment. For the environmental aspects, the existence of several data portals for environmental surveys will allow the production of a quantified assessment of the initial environmental status. The initial environmental status will be the reference to which will be compared the environmental status post-installation of the energy devices. The social impact functions that are proposed contain a group of quantifiable functions too. Environmental and social impacts are indeed site dependent. However, the proposed functions are widely applicable such as the carbon footprint, the number of employed persons etc.
"Similarly, the DTOceanPlus tools mostly deal with technical-led engineering activities, but social and environmental aspects are very site dependant and involve lots of other skills. It was suggested that this is also well covered by other work."	
"Environmental issues for marine energy deployments have been shown to be not a significant issue at many sites, even though these are important."	The environmental issues might be regional/country dependent. In France for instance, the environmental impact assessment is key for the successful progress of an ocean energy project.
Stakeholder iii-1 noted that it is "difficult to automate the assessment of environmental aspects of a project", although a software tool can possibly assess the likely costs for conducting the required environmental assessments.	We will investigate the possibility of having a tool that can possibly assess the likely costs for conducting the required environmental assessments.

6.6.3 APPLICATION OF THE ENVIRONMENTAL AND SOCIAL ACCEPTANCE TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

6.6.3.1 USE THROUGHOUT PROJECT LIFECYCLE

The Environmental and Social Acceptance module can be used throughout project lifecycle and at different levels of complexity of the tool. When considering the chronological phases of the project accounted for in the deployment tool (i.e. design, procurement, construction, installation, operation and decommissioning), all operation and maintenance phases from construction to decommissioning can potentially have an environmental impact related to the presence of vessels and equipment during these periods. These pressures can be physical, chemical or biological and can disturb species and special habitats in the area. Although the environmental impact is most probably related to the advanced stages of a project (i.e. construction, installation, operation and decommissioning), the social acceptance impact can occur earlier in the project lifecycle. From the moment a project is publicly announced, the social impact of the project can be assessed and monitored. It is thus important to consider social acceptance functions at the earliest stages. For social acceptance, several criteria will be of importance, such as economic impacts (e.g. job creation, energy production) or environmental impacts (e.g. carbon footprint, impacts on local biodiversity and iconic species). Some of these functions can be applied at the earliest levels of complexity of the tool (i.e. levels related to TRL scale: Early, Mid and Late).

6.6.3.2 DEALING WITH UNCERTAINTY AND INCOMPLETE DATA

The input data available and/or its uncertainty is dependent on the project lifecycle (before the project start and from deployment to decommissioning stages).

Before the project starts, the initial environmental status assessment is of high importance in order to have an environmental reference state as a comparative basis for later environmental impact assessments. Data used for the initial status assessment has two possible origins, either (1) data collected by the project developers to produce an initial environmental status or (2) data from open-access online databases. The complexity of the conducted assessment is dependent on the availability of these data. However, open-access online databases are more and more developed in the context of international commitments and European directives (e.g. Aichi targets, Marine Strategy Framework Directive) that targets reduction in environmental and socio-economic impacts of human activities by producing initial state assessments. An initial environmental assessment is thus feasible in almost all the European marine waters using open-access online databases such as the scientific survey campaigns data for fish and invertebrate species[4], data on plankton[5], marine mammals, seabirds, elasmobranchs and other biological compartments[6] as long as human activities[7]. These online data sets could be partial datasets which increases the uncertainty of the environmental and social impact assessment.

After the project start, and at all its stages of progress (from conception to decommissioning), data sources will be of various origins such as (1) the DTOceanPlus modules for Array, technology and site characteristics (e.g. depth, temperature or chemical pollutant). This data is mainly used to feed functions of the “stressor” categories. (2) the data collected by the project developers for the monitoring of environmental impact assessment, (3) the scientific literature which can be used to produce potential scenarios of the environmental impact of ocean energy installations and (4) data from open-access online databases. Depending on data availability and its uncertainty, these various data sources can support progress towards the most achievable environmental and social acceptance impact.

[4] http://www.ices.dk/marine-data/data-portals/Pages/DATRAS.aspx
[5] https://www.cprsurvey.org/data/data-request-form/
[6] http://www.emodnet.eu/biology
[7] http://www.emodnet.eu/human-activities

Finally, the scoring allocation system of the environmental and social acceptance impact has a level of confidence related to its data availability. The environmental and social acceptance impact is based on three main steps (1) quantification of the 'pressure' generated by the stressors, (2) the basic qualification of the occurrence (or absence) of receptors and (3) the qualification of the seasonal distribution of receptors. Each step has a confidence value that is related to the existence or not of data. If the user is able to provide details for the three steps, the level of confidence related to the environmental and social acceptance impact will be the highest. If the user is able to provide details only for the first step, the level of confidence related to the environmental and social acceptance impact will be the lowest.

6.6.3.3 USE IN STRUCTURED INNOVATION AND STAGE GATE DESIGN TOOLS

Social acceptance of a project intervenes early in the project development process. Blockages can have an impact on ocean energy project feasibility in due time. It is therefore important to consider social and environmental impacts at the earliest stage of a project conception. Interaction between the Environmental and Social Acceptance module and the Structured Innovation and Stage Gate design tools should be investigated, in order to secure best practice for environmental and social acceptance impacts of projects.

As the Stage Gate design tool will be assessing technologies to inform decision-making for the users, including public sector investors, the Environmental and Social Acceptance tools will be important to this process. Environmental and social assessments at the concept stage would be very valuable to quantify, for instance, the carbon footprint of manufacturing the main materials identified for a given project. Similarly, the Structured Innovation design tool will be identifying attractive new concepts, and the carbon footprint and social impact should be part of this assessment.

6.6.3.4 APPLICATION TO SUB-SYSTEMS, DEVICES, AND ARRAYS

Sub-systems, devices and arrays can have an environmental and social impact during their installation and during the lifecycle of the project. The presence of vessels for their installation, their footprint after installation and other impacts should be investigated by the environmental and social acceptance module.

6.6.3.5 USE BY DIFFERENT USER ROLES

The different user types will have different needs. The different uses may be summarised in Table 6.8.

TABLE 6.8: ENVIRONMENTAL AND SOCIAL ACCEPTANCE TOOLS USE BY DIFFERENT USER ROLES

Technology Developers	Project developers	Public & Private Investors
▫ Assess and reduce the environmental impact of developed technologies, ▫ Increase technology acceptance by increasing social acceptance (e.g. development of local high technological industries).	▫ Produce an initial environmental status assessment prior to project installation (as a reference status), ▫ Assess the environmental impacts that are associated with a given logistics and maintenance solution (develop an iterative approach of the environmental and social acceptance module to give a feedback on the various impacts according to various scenarios), ▫ Communication - Increase project acceptance by increasing social acceptance (e.g. socio-economic impacts such as job creation), ▫ Monitoring – Monitor social acceptance at all stages of project development (e.g. evolution of social opinion)	▫ Evaluate environmental and socio-economic impacts on the local communities.

6.6.4 INTERFACES

6.6.4.1 GENERAL TYPES OF DATA TO BE CONSIDERED

Four major input categories can be identified as data sources:

- The DTOceanPlus modules for Array, technology and site characteristics (e.g. depth, temperature or chemical pollutant). This data is mainly used to feed functions of the "stressor" categories.
- Data collected by the project developers for the monitoring of environmental impact assessment,
- Scientific literature which can be used to produce potential scenarios of the environmental impact of ocean energy projects,
- Data from open-access online databases.

6.6.4.2 REQUIREMENTS FOR OTHER DTOCEANPLUS TOOLS

Several inputs are expected from the other DTOceanPlus modules such as:

1. Array characteristics (e.g. number of devices and device positions)
2. Technology characteristics (e.g. mooring type and dimension or chemical pollutant)
3. Site characteristic (e.g. depth, temperature or soil type)
4. Energy delivery (e.g. energy produced)

The environmental and social acceptance module will produce an assessment of the impacts associated with a given technology, logistics and maintenance solution. By applying an iterative approach of this module, results can be used to revise the technical choices in a way to reduce the environmental impacts and increase social acceptance.

6.6.4.3 EXTERNAL INTERFACES

Environmental and social acceptance data should be ideally locally collected to produce initial environmental and social acceptance impacts of a given project and to monitor their evolution during project lifecycle. However, in case of lack of data, it could be advantageous to integrate environmental and social databases, which could provide rough but good enough estimates for preliminary environmental and social acceptance impacts.

Scenarios of future impacts of array devices installation on local environment is achievable with trophic models (e.g. Ecopath model). This allows to have projections over 10, 20, 30 years for instance and see how the environmental ecosystem evolve after array installation. This scenario production can be useful for project developers and investors. Although not part of the DTOceanPlus scope, the option of linking such models to DTOceanPlus will be investigated.

6.6.5 KEY LIMITATIONS OR EXCLUSIONS

- Data availability is the major limitation for environmental and social acceptance module. The least expectation would be to have data only from other DTOceanPlus modules which would give a limited vision of the environmental and social impacts. The more data is available, the more accurate is the assessment that would be produced.
- An ideal tool should provide GIS interfaces and adapted functionalities to spatially assess environmental and social impact.
- As raised in the user consultation, environmental and social issues are very location dependent and do not completely fall in the scope of a software which deal mostly with technical activities.

7. CONCLUSIONS

A coherent set of requirements have been developed for the DTOceanPlus suite of design tools based on analysis of gaps between the current state-of-the-art tools, learning from the DTOcean project, and the stakeholder expectations identified in the user consultation exercise [6]. These include functional, operational, user, interfacing, and data requirements. They will act as user specifications for the tool development work packages, and will focus the development effort to best meet the needs of the ocean energy industry.

7.1 NEXT STAGES

Building on the requirement set out in this document, detailed specifications for the software development will be produced in tasks T3.1, T4.1, T5.1, T6.1, and T7.1, as shown in Figure 7.1. Following on from this, the DTOceanPlus software development will proceed in a staged approach, producing alpha, beta, and release versions of the design tools in months 24, 30, and 36 respectively.

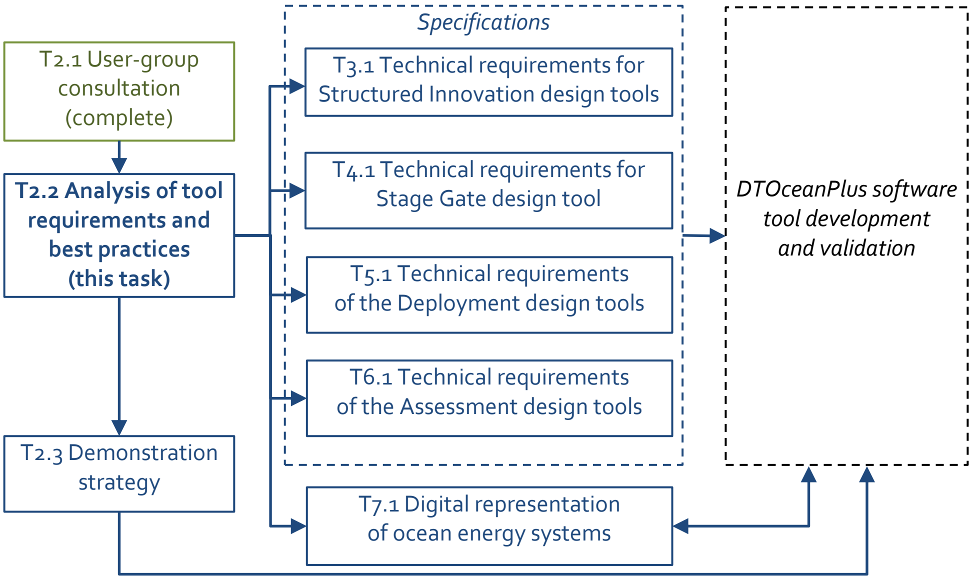

FIGURE 7.1: GRAPHICAL SUMMARY OF SOFTWARE SPECIFICATION TASKS (EXTRACTED FROM GRAPHICAL PRESENTATION OF THE PROJECT [4])

8. REFERENCES

[1] L. P. Sullivan, " Quality Function Deployment," *Quality Progress, ASQC*, pp. 39-50, 1986.

[2] M. Dale and C. Best, "Quality techniques in action," *Automotive Engineer*, vol. 13, no. 4, pp. 44-7, 1988.

[3] European Commission, "Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment | Projects | H2020 | CORDIS," 17 January 2018. [Online]. Available: https://cordis.europa.eu/project/rcn/214811_en.html. [Accessed 6 August 2018].

[4] DTOceanPlus Consortium, "DTOceanPlus Proposal: Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment," 2017.

[5] The University of Edinburgh; Tecnalia; Energy Sysytems Catapult; Wave Energy Scotland; France Energies Marines; WavEC; Aalborg University; EDF; Open Cascade, "TN2.2 Annex to Functional requirements – detailed analysis of user requirements for different tools," 2018.

[6] D. R. Noble and E. Medina-Lopez, "DTOceanPlus Deliverable D2.1 Results from user consultation," DTOceanPlus Consortium, 2018.

[7] DTOcean, "DTOcean User Manual (Release)," 2016.

[8] Nova Innovation, "EnFAIT Project Overview," 2018. [Online]. Available: https://www.enfait.eu/. [Accessed 24 July 2018].

[9] E. Medina-Lopez and T. Bloise-Thomaz, "EnFAIT D10.3 DTOcean : Scenario Definition & Performance Metrics," EnFAIT Project, Edinburgh, 2018.

[10] R. Crozier, "e-Drive launches new Wave Systems Simulation Toolbox at ICOE conference 2018, Cherbourg France," 22 May 2018. [Online]. Available: https://www.edrive.eng.ed.ac.uk/news/20180522/e-drive-launches-new-wave-systems-simulation-toolbox-icoe-conference-2018-cherbourg. [Accessed 7 Sept 2018].

[11] LHEEA Ecole Central Nantes, "NEMOH-Presentation," 22 Nov 2017. [Online]. Available: https://lheea.ec-nantes.fr/software-and-patents/nemoh-presentation-217691.kjsp. [Accessed 10 Sept 2018].

[12] Wikipedia, "OpenFOAM," 14 Aug 2018. [Online]. Available: https://en.wikipedia.org/wiki/OpenFOAM. [Accessed 10 Sept 2018].

[13] SWAN, "Features of SWAN," [Online]. Available: http://swanmodel.sourceforge.net/features/features.htm. [Accessed 10 Sept 2018].

[14] Open Telemac-Mascaret Consortium, "The TELEMAC-MASCARET modelling system," [Online]. Available: http://www.opentelemac.org/index.php/presentation. [Accessed 7 Sept 2018].

[15] Wave Energy Scotland, "Operations and Maintenance Simulation Tool - User Guide," 2017.

[16] National Oceanic and Atmospheric Administration, "WAVEWATCH III Model," 3 Nov 2016. [Online]. Available: http://polar.ncep.noaa.gov/waves/wavewatch/. [Accessed 8 Oct 2018].

[17] National Renewable Energy Laboratory and Sandia Corporation, "Docs » WEC-Sim (Wave Energy Converter SIMulator)," 2015. [Online]. Available: https://wec-sim.github.io/WEC-Sim/. [Accessed 7 Spet 2018].

[18] ANSYS, "ANSYS Aqwa," [Online]. Available: https://www.ansys.com/en-gb/products/structures/ansys-aqwa. [Accessed 10 Sept 2018].

[19] ANSYS, "ANSYS Fluent," [Online]. Available: https://www.ansys.com/en-gb/products/fluids/ansys-fluent. [Accessed 10 Sept 2018].

[20] Bureau Veritas, "ARIANE," [Online]. Available: https://www.veristar.com/portal/veristarinfo/detail/software/Seakeeping%20and%20Mooring%20Analysis/ARIANE/moor. [Accessed 8 Oct 2018].

[21] Principia, "DEEPLINES," [Online]. Available: http://www.principia-group.com/blog/product/produit-deeplines/. [Accessed 10 Sept 2018].

[22] Wood, "Flexcom," [Online]. Available: https://www.woodgroup.com/what-we-do/view-by-products-and-services/digital-solutions/flexcom. [Accessed 10 Sept 2018].

[23] Jeremy Benn Associates, "ForeCoast Marine," [Online]. Available: https://www.forecoastmarine.com/. [Accessed 12 Sept 2018].

[24] Bureau Veritas , "HYDROSTAR," 31 May 2018. [Online]. Available: https://www.veristar.com/portal/veristarinfo/detail/downloads/Calculation%20Software/hydrostar. [Accessed 8 Oct 2018].

[25] James Fisher and Sons, "Mermaid," [Online]. Available: https://www.james-fisher.com/services/marine-services/mermaid/. [Accessed 12 Sept 2018].

[26] DNV-GL, "TidalBladed," [Online]. Available: https://www.dnvgl.com/services/tidalbladed-3799. [Accessed 10 Sept 2018].

[27] DNV-GL, "TidalFarmer," [Online]. Available: https://www.dnvgl.com/services/tidalfarmer-3774. [Accessed 7 Sept 2018].

[28] WAMIT Inc, "Technical Description," [Online]. Available: https://www.wamit.com/techdescription.htm. [Accessed 10 Sept 2018].

[29] DNV-GL, "WaveDyn," [Online]. Available: https://www.dnvgl.com/services/wavedyn-3800. [Accessed 7 Sept 2018].

[30] DNV-GL, "WaveFarmer," [Online]. Available: https://www.dnvgl.com/services/wavefarmer-3772. [Accessed 7 Sept 2018].

[31] Exceedence, "Our software is a key tool for the Renewable Energy sector," [Online]. [Accessed 7 Sept 2018].

[32] Ocean Wave Venture , "Wave Venture TE," [Online]. Available: http://www.wave-venture.com/software/. [Accessed 13 Sept 2018].

[33] M. Z. Homer Rahnejat, "The "QFD/FMEA interface"," *European Journal of Innovation Management*, p. 18, 1998.

[34] L. P. Sullivan, "Quality Function Deployment," *Quality Progress, ASQC*, vol. 19, no. 6, pp. 39-50, 1986.

[35] D. De Vera, T. Glennon, A. Kenny, M. Khan and M. Mayer, "An automotive case study," *Quality Progress*, vol. 21, no. 6, pp. 35-38, 1988.

[36] N. Egbert, "Design for Process Excellence- Ensuring timely and cost-effective solutions," in *International Congress of the aeronautical sciences (ICAS)*, 2008.

[37] P. C. W. P. Kerley, "Chapter 13: Modelling the Quality of Engineering Designs," in *Modelling and Management of Engineering Processes*, Springer, 2010.

[38] J. Weber and D. Laird, "Structured Innovation of High-Performance Wave Energy Converter Technology," in *2015 European Wave and Tidal Energy Conference*, Nantes, 2015.

[39] WES, "Project SEAWEED," 22 10 2018. [Online]. Available: http://www.waveenergyscotland.co.uk/strategic-activity/strategic-activity-2/structured-innovation/project-seaweed-1/.

[40] CGMA, "Quality Management tools," 11 06 2013. [Online]. Available: https://www.cgma.org/resources/tools/essential-tools/quality-management-tools.html.

[41] G. Barczak, A. Griffin and K. Kahn, "PERSPECTIVE: Trends and Drivers of Success in NPD Practices: Results of the 2003 PDMA Best Practices Study," *The journal of Product Innovation Management*, vol. 26, pp. 3 - 23, 2009.

[42] R. G. Cooper and S. J. Edgett, "Best Practices in the Idea-to-Launch Process and it's Governance," in *Research Technology and Management*, 2012, pp. 43 - 54.

[43] T. Jones, in *Innovating at the Edge*, 2012, p. 47.

[44] R. Kohli, J. Fishman and M. Hyatt, "Decision Gate Process for Assessment of a Technology Development Portfolio," 11 9 2012. [Online]. Available: https://ntrs.nasa.gov/search.jsp?R=20120013467. [Accessed 20 9 2018].

[45] V. Narayanan and G. C. O'Connor, in *Encyclopedia of Technology and Innovation Management*, 2010, p. 158.

[46] T. Jahn and H. Binz, "Early Phase Project Maturity Controlling of Automotive Systems in the Automotive Industry," *International Conference on Engineering Design*, 2007.

[47] H. Oeltjenbruns, U. Bracht, G. Neidlein and M. F. e. al., "Standardized Product Creation Process in Commercial Vehicle Development," *SAE Technical Paper* , 2000.

[48] "Wave Energy Scotland website," [Online]. Available: http://www.waveenergyscotland.co.uk/ . [Accessed 25 9 2018].

[49] The United States Department of Energy , "Existing Ocean Energy Performance Metrics," [Online]. Available: https://eere-exchange.energy.gov/FileContent.aspx?FileID=89a224a1-6062-4567-a52d-66ddcaoaa158. [Accessed 25 9 2018].

[50] International Energy Agency - Ocean Energy Systems, "Task 12: Stage Gate Metrics International Framework for Ocean Energy," [Online]. Available: https://www.ocean-energy-systems.org/oes-projects/task-12-stage-gate-metrics-international-framework-for-ocean-energy/. [Accessed 25 9 2018].

[51] Wave Energy Scotland, "Knowledge Library: International Metrics Development," [Online]. Available: https://library.waveenergyscotland.co.uk/other-activities/metrics/. [Accessed 25 9 2018].

[52] Stage-Gate International , [Online]. Available: https://www.stage-gate.com/the-stage-gate-navigator/. [Accessed 25 9 2018].

[53] Gensight, [Online]. Available: http://www.gensight.com/stage-gate-functions/. [Accessed 25 9 2018].

[54] One2Team, [Online]. Available: https://one2team.com/stage-gate-process/. [Accessed 25 9 2018].

[55] Ocean Energy Europe; France Energies Marines; Tecnalia; The University of Edinburgh, "DTOcean Deliverable 8.5: First Workshop Report," 2015.

[56] ETI, "Offshore Wind Floating Demonstration Project FEED Study," The Energy Technologies Institute, Loughborough, 2014.

[57] A. Clamen, "Reducing the time from Basic Research to Innovation in the chemical Sciences: A workshop Report to the Chemical Sciences Roundtable," National Academies Press (US), Washington (DC), 2003.

CONTACT DETAILS

Mr. Pablo Ruiz-Minguela

Project Coordinator, TECNALIA

www.dtoceanplus.eu