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

Deliverable D4.1

Technical requirements for the implementation of a world-class Stage Gate Assessment Framework in Ocean Energy

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EXECUTIVE SUMMARY

This document, D4.1 Technical requirements for the implementation of a world-class Stage Gate Assessment Framework in Ocean Energy, 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 aggregation (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 tools in mature industries and those in the ocean energy industry, learning from the original DTOcean project, and the stakeholder expectations identified in the user consultation exercise. The technical requirements in this document are translated from the general requirements for the overall suite of tools, and specific requirements (functional, operational, user, interfacing, and data) for the Stage Gate design tool that will be developed as part of this project.

This document, D4.1, includes a summary of the stage gate process and proposes a Stage Gate design tool as part of the DTOceanPlus suite of tools. A detailed description of the technical requirements of the tool is discussed in addition to the integration of the tool with the underlying platform, the other set of tools (Deployment tools, Assessment tools and Structured Innovation tools), and the digital representations.

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ABBREVIATIONS AND ACRONYMS

AEP	Annual Energy Production
API	Application Programming Interface
CAPEX	Capital Expenditure
ESC	Energy Systems Catapult
FMEA	Failure Modes and Effects Analysis
GUI	Graphical User Interface
HoQ	House of Quality matrix
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)
OLCs	Operational Limits and Conditions
OPEX	Operational Expenditure
PTO	Power Take-Off
QFD	Quality Function Deployment
R&D	Research and development
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
UML	Unified Modelling Language

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 of 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).

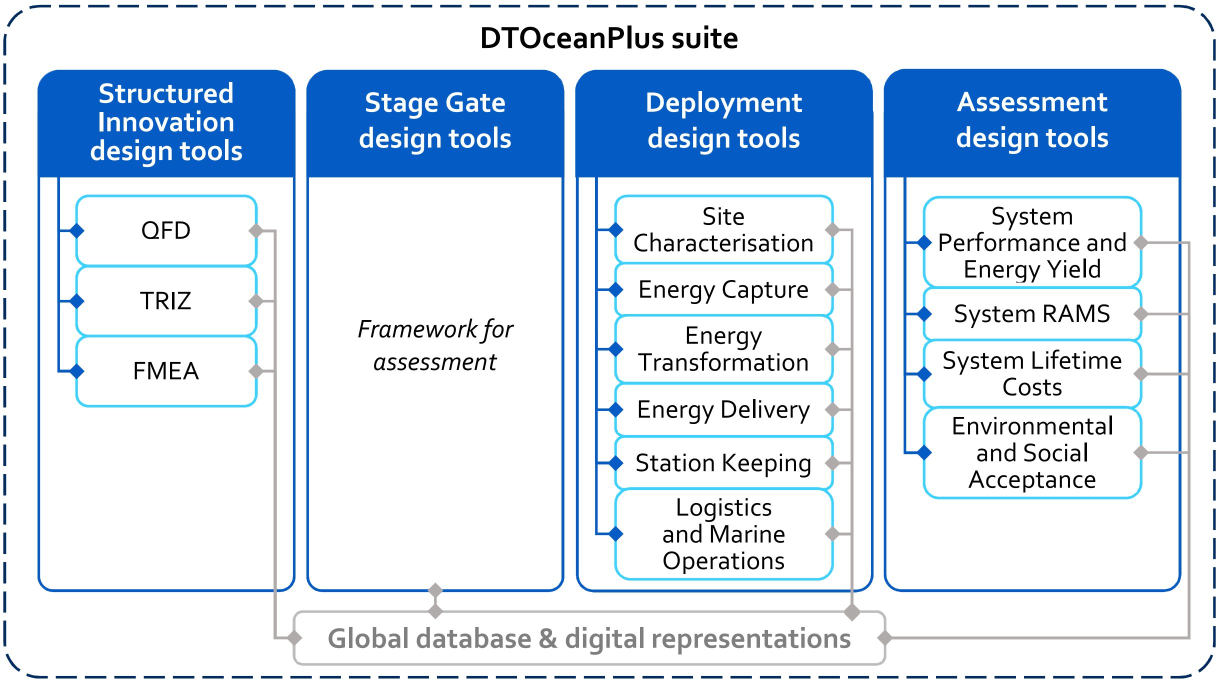

FIGURE 0.1 REPRESENTATION OF THE DTOCEANPLUS TOOLS HIERARCHY

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, including its 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.

Digital Representation — A complete description of the user's project at a given time. It can be seen as a digital version of the real project and therefore it should contain all the needed information to describe the project. It describes all the concepts defined in the DTOceanPlus application (concept creation, contradictions …). Each of these concepts is handled by one of the tools of the application, so it means that the Digital Representation can be seen as an assembly of the extracted data from each tool, and as an export of the current project. This export will be done in a standard format, such as XML or JSON, with a documented structure so that it can be used by other applications. However, the Digital Representation is not a complete export of a DTOceanPlus project. Indeed, as this format is presented as a standard to represent an ocean energy system, it is important that it remains independent from the DTOceanPlus application. Therefore, not all the concepts that are internal to DTOceanPlus application should be exported in the Digital Representation.

Global database — A shared structured dataset containing input data, the digital representations of components to arrays, and accessed by all the design tools. It contains the Reference Database which is a package that contains a list of catalogues. These catalogues can be described as standard references that can be imported from organisations (e.g. list of devices or vessels) or can come from several databases (local or online), or even files (CSV or any format).

User Interface/ Graphical User Interface — "The user interface (UI), is the space where interactions between an end user and a machine occur to allow effective operation and control in order to achieve desired output(s). The graphical user interface (GUI) is a form of UI that allows users to interact with electronic devices through graphical icons and visual indicators, instead of text-based user interfaces[1]".

Local Storage — A structured dataset containing input data only relevant to the Structured Innovation modules. 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 independently with the required data saved in the local storage, but also use data from the database.

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)

[1] https://en.wikipedia.org/wiki/Graphical_user_interface

	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 or design 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.
Evaluation Areas	These are a list of the topics which are to be assessed. Examples of some of these are: Maintainability, Installability and Energy Capture.

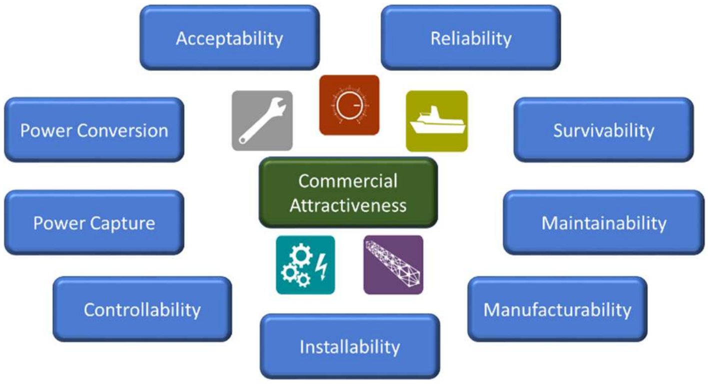

FIGURE 0.2 EXAMPLE OF EVALUATION AREAS IN THE ASSESSMENT OF THE COMMERCIAL ATTRACTIVENESS OF OCEAN ENERGY TECHNOLOGY

Stage gate metric thresholds	These are the user defined performance criteria which must have been achieved for a technology to "pass" a particular metric within a topic area. These may be defined by the users of the tool themselves, or they can be selected from a list of default values. For example, Metric: Mean Time To Failure, MTTF (hours), Threshold: 50000 hours
Stage Activities	These are the activities which have taken place in the development of a technology. For example, this includes "Numerical models have been completed and validated against tank test data", "Small scale physical testing is complete in realistic wave conditions".
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.

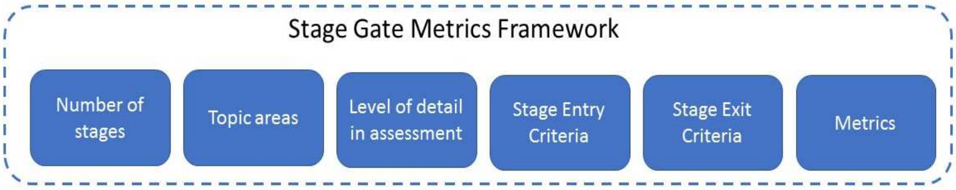

FIGURE 0.3: REPRESENTATION OF A STAGE GATE METRICS FRAMEWORK

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 Subsystem to convert mechanical energy (from Hydrodynamic subsystem) to useful electrical energy. 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 subsystem 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.
Development Expenditure (DEVEX)	All the cost incurred from initiation to implementation of a 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.

Structured Innovation Methodology

A technique to stimulate rigour, organised and consistent innovative thinking, technology selection and impact assessment. This technique combines functions such as understanding the mission, the future vision, the market (including the potential for commercial exploitation, competition, differentiation, social value etc.) and the development of potential solutions. This is broadly described in British Standard BS7000-1, "Design Management Systems, Part 1 – Guide to Managing Innovation" amongst others [3]. The methodology is to be developed in accordance with the concept shown in Figure 0.4:

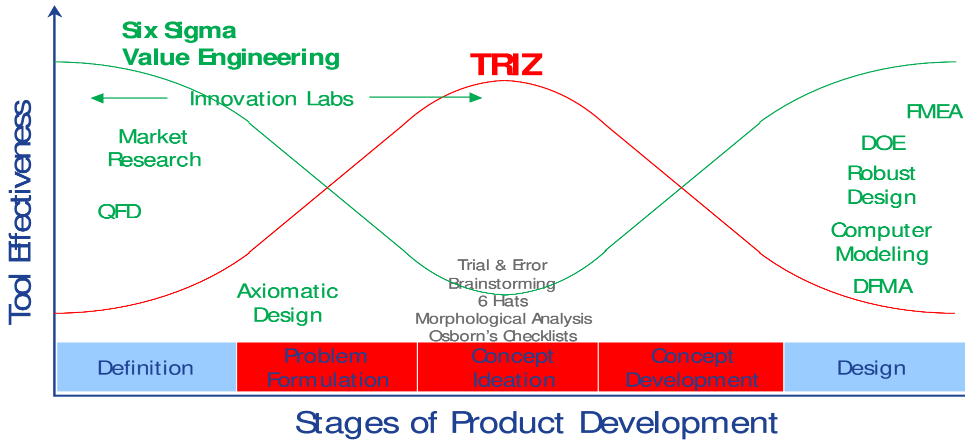

FIGURE 0.4: TOOL EFFECT VS PRODUCT DEVELOPMENT STAGE [4]

1. INTRODUCTION

The DTOceanPlus project will develop an open-source integrated suite of 2nd generation tools for ocean energy technologies [5]. 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 aggregation levels: sub-system, device, and array.

The proposed tools are covered in more detail in section 1.4. At a high level, these will include:

- **Structured Innovation tool**, for concept creation, selection, and design.
- **Stage Gate tool**, 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 4.1 'Technical requirements for ocean energy Stage Gate design tool'. It is one of four concurrent deliverables to produce detailed specifications for the DTOceanPlus software tool development in conjunction with tasks T3.1, T5.1, T6.1, and T7.1 of work packages 3–7, as shown in Figure 1.1.

These deliverables document the current understanding of the requirements at the time of writing. It is inevitable however that some of the specific details of implementation will change over the course of the software development. The full description of the technical specifications of the tools will be published in the technical manuals to accompany the final software release.

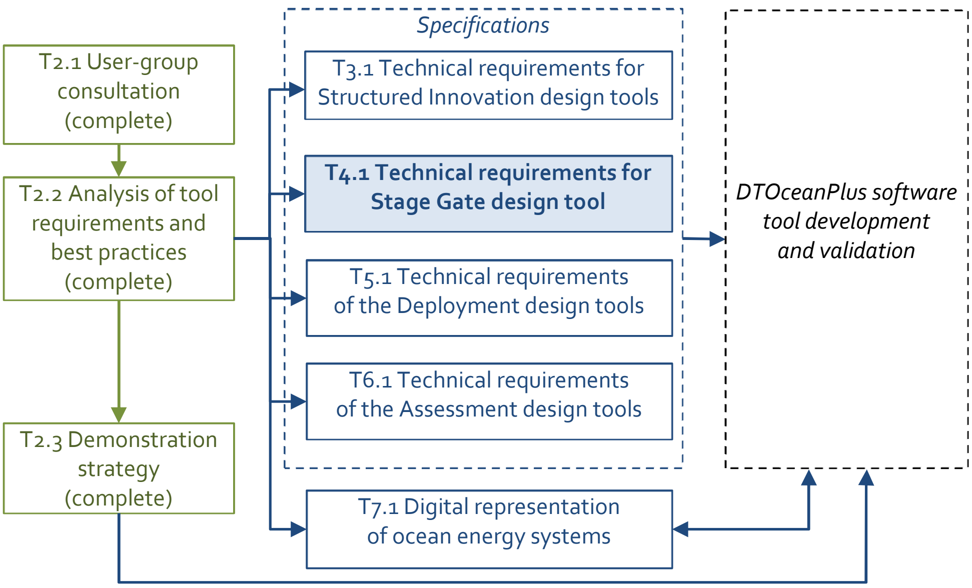

FIGURE 1.1 GRAPHICAL SUMMARY OF SOFTWARE SPECIFICATION TASKS

1.2 OUTLINE OF REPORT

This report specifies the detailed requirements (functional, operational, user, interfacing, and data) for the DTOceanPlus suite of tools.

The remainder of the report is laid out as follows:

- Section 2 outlines the Stage Gate process for technology development
- Section 3 sets out the technical requirements of the Stage Gate design tool.
- Section 4 sets out the technical specifications for the integration of the Stage Gate design tool in the DTOceanPlus suite of tools.
- Finally, section 5 gives conclusions and summarises the next steps.

1.3 TECHNICAL SPECIFICATIONS OF DTOCEAN

The original DTOcean Project 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 [6] 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 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.

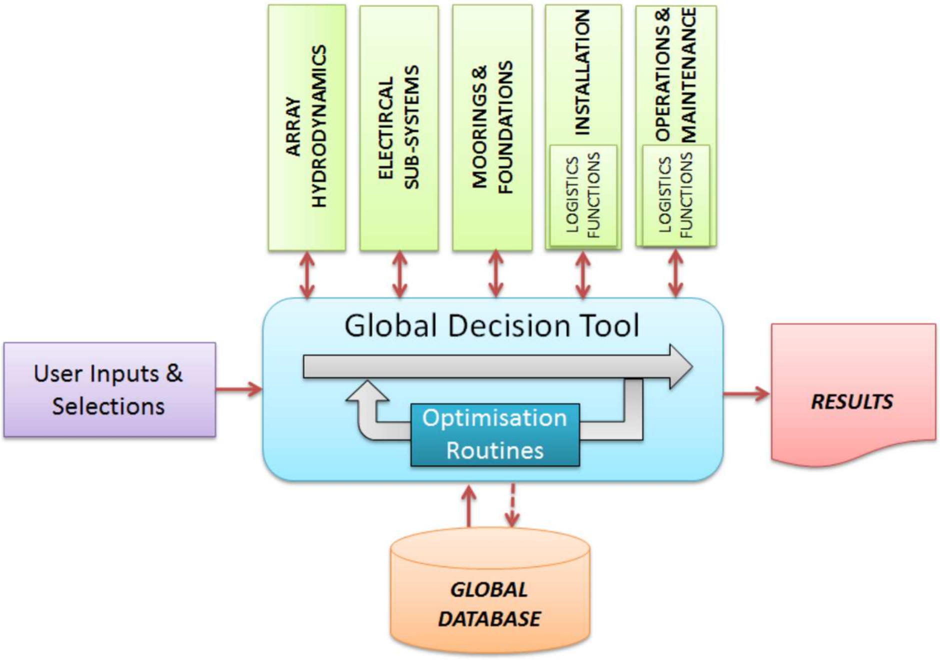

FIGURE 1.2: FUNCTIONAL STRUCTURE OF ORIGINAL DTOCEAN SOFTWARE [6]

1.4 OUTLINE OF THE DTOCEANPLUS SUITE OF TOOLS

The DTOceanPlus software will comprise an integrated suite of 2nd generation design tools, which are summarised below and illustrated at a high level in Figure 1-3. These build upon the tools originally developed in the DTOcean project[2] between 2013 and 2016, and the latest release of DTOcean 2.0[3].

- The Structured Innovation and Stage Gate design tools are new to DTOceanPlus. Based on best practices from the ocean energy and other sectors, they will provide structured methods for concept creation and assessing the progress of technology development through defined stages and stage gates. The Deployment and Assessment Design Tools will be significantly improved from the original DTOcean versions. The whole suite of design tools will be designed to assess various levels of complexity and to be used throughout the project lifecycle.
- **Structured Innovation design tool**, for concept creation, selection, and design, with three modules:
  - Quality Function Deployment (QFD).
  - Theory of Inventive Problem Solving (TRIZ).
  - Failure Modes and Effects Analysis (FMEA).
- **Stage Gate design tool**, using metrics to measure, assess and guide technology development. As part of this, the DTOceanPlus project will develop:
  - A stage-gate structure.
  - Metrics.
  - Tools for measuring success and analysing performance against metrics and thresholds.

[2] Funded under EU FP7 framework Grant Agreement № 60859
[3] https://www.dtoceanplus.eu/Tools/DTOcean-Version-2.0

- 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**.
  - A digital representation will be developed to provide a standard framework for the description of sub-systems, devices and arrays. This will be a common digital language for the entire sector.
  - The global database will contain catalogues of reference data from various sources.

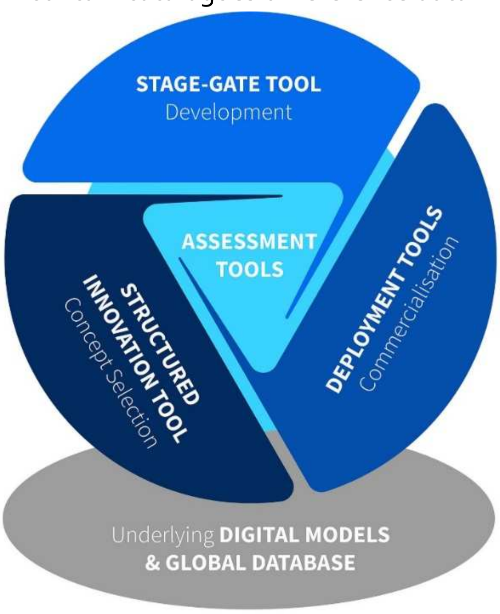

FIGURE 1-3: REPRESENTATION OF DTOCEANPLUS TOOLS.

The technical requirements for the Stage Gate design tool are set out in this document. Accompanying deliverables set out the technical requirements for the other design tools as follows: D3.1 Structured Innovation, D5.1 Deployment, and D6.1 Assessment. Further details of the common digital models or digital representation will be proposed in D7.1 'Standard data formats for the Ocean Energy Sector' due to be published in autumn 2019.

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 more detailed technical assessments, e.g. for project consenting.

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 deployment can be split into three stages for clarity (Early, Mid, and Late), as described in Table 1-1. These can broadly be linked to the widely-used TRL scale [7]. Those three stages address all the phases described above, with different levels of complexity accounted for in the project definition.

TABLE 1-1. 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 aggregation, 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.

Where applicable, the design tools will consider details of assemblies and components, however they will not be designed to assess technologies at this level.

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

- The Structured Innovation design tool 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 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.
- 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.
- The Deployment design tools provide optimised solutions and layouts for the deployment of ocean energy technologies, and define all the technical design specification to run the Assessment design tools for the evaluation of metrics.
- Finally, the 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 to assess the performance of technologies throughout the project lifecycle, as a technology matures; when there is little to no data available about a technology at the concept definition stage, and more data from testing and simulations at the design and deployment stage.

Table 1-2 below outlines how the assessment method changes through these different stages, depending on the data available. 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 of D2.2 Functional requirements and metrics of 2nd generation design tools [8].

TABLE 1-2 INCREASING TOOL COMPLEXITY FOR DIFFERENT DEVELOPMENT STAGES.

Stage & approx.TRL	Data availability	Assessment method
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. ▫ High-level quantitative assessments from the Assessment and Deployment design tools. ▫ Scoring of a technology by qualitative assessment from an expert assessor.
Mid stage (TRL 4–6)	Low complexity; limited data available	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.
Late stage (TRL 7-9)	Full complexity; makes use of detailed information about the project.	More detailed 'advanced' quantitative assessments through the Deployment and Assessment design tools.

2. BACKGROUND – TECHNOLOGY ASSESSMENT IN A STAGE GATE PROCESS

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 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. This section introduces some of the important considerations associated with the definition of a stage gate assessment process and the impacts of these on the technical requirements presented in Section 3.

2.1 TYPES OF ASSESSMENT IN OCEAN ENERGY

The Stage Gate design tool, supported by the Assessment design tools, will provide a consistent assessment process for ocean energy subsystems, energy capture devices and arrays. This assessment process will support the decision-making activity of several user types, who all wish to have the best available information to support their decisions. Ideally, this information would consist of a completely objective assessment of how well a technology performs against key metrics or criteria, however, the information required to carry out a fully objective, quantitative evaluation is not always available, especially at the early stages (Low detail) of the development process. This means that the assessment approach must change according to the development stage and the information available. Figure 2.1 presents the various types of assessment which can be used throughout the technology or array development process, from low detail, low accuracy qualitative assessment, through to fully objective, high-detail and high-accuracy evaluation.

Assessment approaches can be qualitative or quantitative (or a combination) and both are usefully employed in ocean energy. The subjectivity of qualitative methods (i.e. an expert assigning a numerical score to a narrative description of a technology) can be managed by using clear, specific scoring criteria. These scoring criteria bring real improvement when devised using industry best practise and a clear understanding of fundamental technology requirements. Despite such management, subjectivity can always remain and be affected by the technology developers' ability to describe their technology and explain their achievements – however, subjectivity can also be reduced by having a panel of experts involved in a review. Examples of this type of managed scoring can be found in the Wave Energy Scotland stage gate programme and the Technology Performance Level evaluation process developed by NREL and Sandia under the Wave-SPARC programme in the USA [9] [10].

Where quantitative approaches are used, the method applied to calculate the metrics can be varied according to the availability and detail of data on the candidate technology. This can be achieved by using proxy metrics at earlier stages, or by replacing unavailable data with typical or benchmark values from experience in the sector.

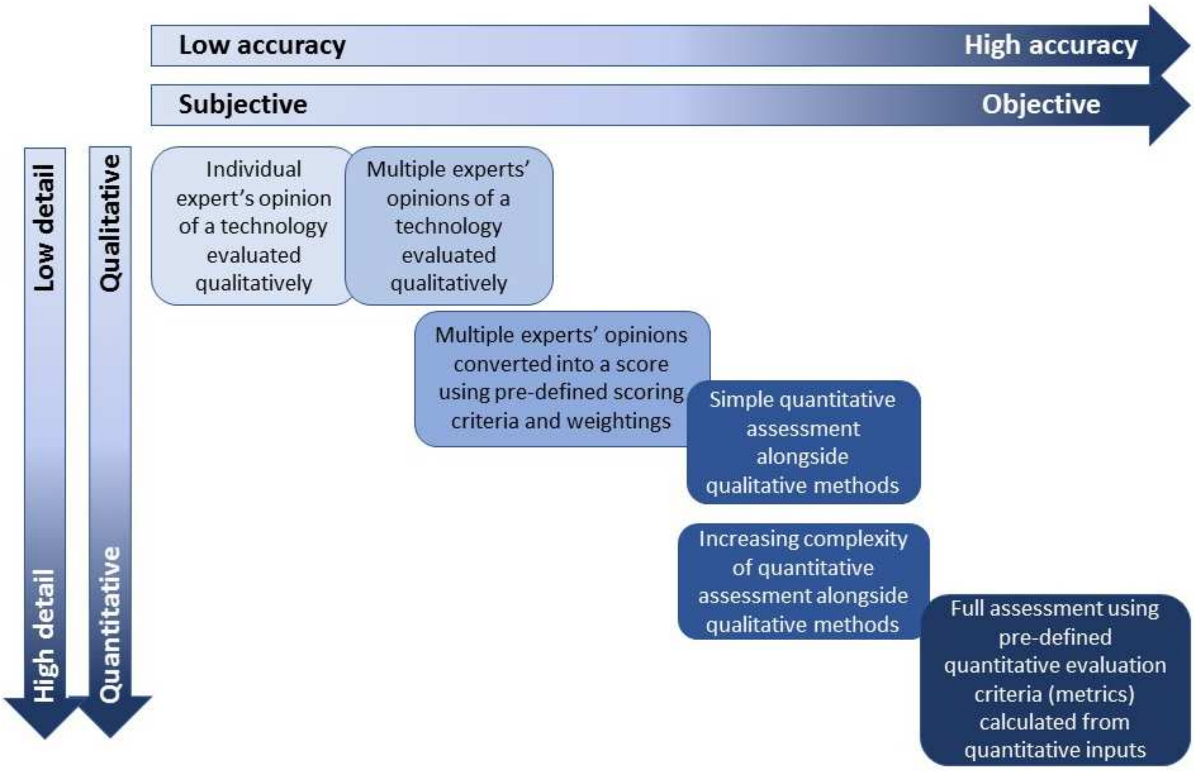

FIGURE 2.1 EXAMPLES OF ASSESSMENTS WHICH ARE QUALITATIVE/ QUANTITATIVE AND SUBJECTIVE/ OBJECTIVE

DTOceanPlus covers a range of the types of assessment presented in Figure 2.1, with the Structured Innovation tool encompassing a combination of quantitative and scored qualitative assessments, and the Stage Gate design tool leading the assessment towards quantitative, objective assessments through a range of levels of complexity. It is important to note that a combination of qualitative and quantitative evaluations is often valuable, with narrative information adding to the assessors' (potentially investors) understanding of a technology's development trajectory. This can add to the confidence they derive from the detailed quantitative assessment results.

2.2 SOURCES OF TECHNOLOGY ASSESSMENT EXPERIENCE

The DTOceanPlus project has benefitted from a range of sources of technology assessment experience, either through direct partner contributions, incoming collaborations or external activity of project partners.

- Wave Energy Scotland (DTOceanPlus Partner)
  - WES is running a research, development and innovation programme [9] which is based around a competitive stage gate process. WES has significant experience of technology evaluation and continuously improvement application of Evaluation Criteria.
  - WES is delivering an international collaboration activity on behalf of the European Commission, in collaboration with the US Department of Energy, under Task 12 of the International Energy

Agency, Ocean Energy Systems (IEA-OES) group. The task aims to find consensus on assessment of ocean energy technologies, by creating an internationally agreed set of ocean energy metrics. This knowledge and experience is being transferred to the DTOceanPlus project to ensure that the suite of tools aligns with international consensus.

- The DTOceanPlus Consortium (DTOceanPlus Partners)
  - The consortium itself contains significant and wide-ranging knowledge and experience on the assessment of ocean energy technologies and arrays, with specific knowledge being applied to the individual assessment areas of Performance & Energy Yield, Environmental & Social Acceptance, Lifecycle Cost Assessment and Reliability, Availability, Maintainability & Survivability.
- US Department of Energy (Collaborators and DTOceanPlus Guidance Providers)
  - The US Department of Energy (US DOE) funds technology Research and Development through specifically targeted Funding Opportunity Announcements (FOA) and has gathered valuable experience of evaluation and selection processes for ocean energy. The DOE also ran the flagship Wave Energy Prize [11], a competition managed through application of key Evaluation Criteria.
  - The DOE funds Sandia National Laboratories and National Renewable Energy Laboratory (NREL) along with partners to complete the Wave-SPARC [10] programme (Sandia and NREL). This programme has developed Structured Innovation processes, particularly focusing on methods for holistic evaluation of technologies through the Technology Performance Level assessment.
- The European Commission (Lead of the IEA-OES Task 12 on Metrics, being delivered by WES)
  - Through various research and innovation actions, the Commission has funded a series of activities which have contributed to the development of evaluation techniques for ocean energy. In particular, through the European Energy Research Alliance (EERA Ocean Energy JP [12] and the Ocean ERA-NET [13] funding schemes, WES, DOE and the Sustainable Energy Authority of Ireland ran a series of workshops aiming to develop consensus on Evaluation Criteria (Metrics) for the ocean energy sectors. The Energy Technology and Innovation Platform, ETIP Ocean [14], has run a series of webinars and workshops, some of which focussed on Evaluation Criteria (Metrics).
- The wider IEA-OES community (Contributing to IEA-OES Task 12, being delivered by WES)
  - The IEA-OES ran a workshop on measurement of success in ocean energy and the approach to Task 12 at its Executive Committee Meeting, alongside the International Conference on Ocean Energy (ICOE) 2018. This provided valuable insight into the application of evaluation techniques in the global sector. Valuable input from other IEA-OES partners will be gathered through the process of reviewing Task 12 deliverables.

2.3 STAGE GATE METRICS FRAMEWORK

A stage gate assessment process for development of ocean energy technologies and arrays is defined by the content of a Stage Gate Metrics Framework, containing details of the following parameters:

- The number of stages
  - The number of stages the technology or array will pass through during the development process
- Stage activities
  - The research, development and demonstration activity that should be carried out during the prescribed stages
- Evaluation Areas
  - The key areas in which the user wishes to measure the success of ocean energy technology to demonstrate progress and performance
- Metrics
  - The specific parameter(s) used to evaluate how well a technology performs in the Evaluation Areas

Alongside the framework, thresholds can be applied, to allow comparison of the assessment result in specific metrics against the state-of-the-art, for example. Such a framework will be developed and used within the DTOceanPlus Stage Gate design tool.

2.4 SETTING TECHNOLOGY EVALUATIONS IN CONTEXT

Another important consideration required to develop the technical requirements of the DTOceanPlus suite of tools is that of the various levels of aggregation to be covered. DTOceanPlus will provide assessments of sub-systems, energy capture devices and arrays of devices as defined in a Stage Gate Metrics Framework, however some key metrics can only be fully assessed at array level. Therefore, a sub-system must be placed in context of an energy capture device and that in turn placed in the context of an array and a project, to be able to evaluate the impact of that sub-system on array level performance.

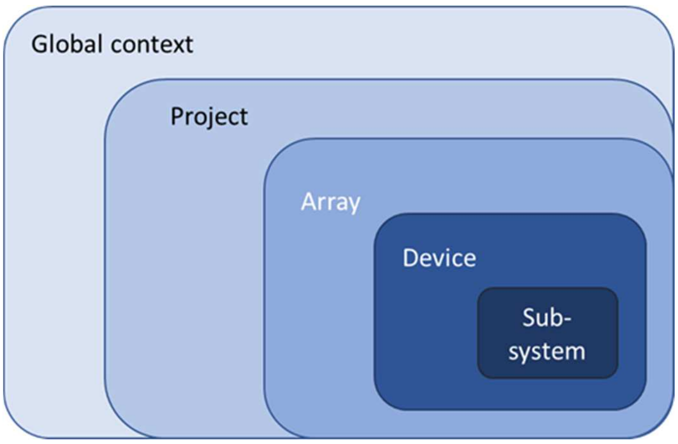

FIGURE 2.2 THE CONTEXT OF DIFFERENT LEVELS OF AGGREGATION

An example of this is the evaluation of Levelised Cost of Energy for a Power Take Off. At an early stage, at sub-system level, assumptions will need to be made on device type, array size/location and project parameters and these assumptions should be clearly defined by users as part specific of evaluation criteria calculations.

DTOceanPlus will develop a process for defining and applying context to the assessment process, as can be seen in Deliverable D7.1.

2.5 REFERENCE DATA IN THE ASSESSMENT PROCESS

As mentioned previously, the assessments taking place in a stage gate process require:

- Context such that assessment can be carried out at three levels of aggregation – subsystem, device and array.
- Assessment at varying levels of complexity depending on the stage of development and the amount of information available
- Comparison of assessment results against thresholds, for example the state-of-the-art or a commercial acceptance target, to provoke innovation where shortfalls are identified

For the assessment process to deliver these functionalities, default or example reference data will be required to complement the user data input and allow the Deployment and Assessment design tools to run. Each functionality requires different reference data types, as discussed in the following sections.

2.5.1 OPERATION OF TOOLS AT THREE LEVELS OF AGGREGATION

The suite of DTOceanPlus will consider subsystems, devices and arrays (as shown in Figure 2.2), but not all users will be operating at all these levels of aggregation e.g. some users may be designing an energy capture device but have not yet considered the required subsystems or evaluated the behaviour or performance of the device in an ocean site or array. Despite this, some of the parameters or metrics required to assess that energy capture device require, by definition, knowledge of array installation, project parameters and the global context or state of the industry. In such cases, reference data is required to put the energy capture device in context of an array, by providing example data to allow downstream tools to run.

An example is the assessment of the LCOE of an energy capture device – evaluation of this metric requires knowledge of the balance of plant (additional CAPEX), operations and maintenance logistics (OPEX) and metocean conditions (resource and logistics) and these require knowledge of site and array design. LCOE calculation also requires knowledge of project level parameters such as project life and discount rate.

2.5.2 OPERATION OF TOOLS AT VARYING LEVELS OF COMPLEXITY

Through the technology or array development process, the level of detail of the design and assessment activity increases, and this is mirrored by the complexity of the assessment applied by the tools. At early stages, tool calculation processes could be simplified by using less complicated or proxy parameters, or by using default/example values to substitute those which simply do not exist yet.

2.5.3 COMPARISONS AND PROVOCATION OF THE INNOVATION AND INVENTION PROCESSES

The first two types of Reference Data effectively represent example data, used to allow tools to run when the full suite of input parameters is not available. The third type comes in three forms and is used to set targets and to identify shortfalls and opportunities for innovation.

These values can represent:

- The state of the art
- Commercial acceptance targets
- Ideal technology values – the art-of-the-possible

In some cases, one of these forms will also be used as the "example" reference data discussed in sections 2.5.1 and 2.5.2.

The selection of which reference data to use in a tool run and therefore what reference data should be generated by the DTOceanPlus project, requires understanding of the required user contexts.

3. TECHNICAL REQUIREMENTS OF THE TOOLS

In this section, the technical requirements for all the modules of the Stage Gate design tool developed in DTOceanPlus will be described.

As part of the Agile Modelling approach [15], the technical requirements include a set of non-functional requirements that the software should be able to satisfy in order to accomplish the specific functions to be carried out. Essentially, these involve performance, reliability, and availability issues. In the following sections, the discussion is focused on not-pure technical requirements, rather than specific technologies. This prevents requirements from becoming obsolete as technologies change. Indeed, the following sections make reference to the data requirements and the main classes of technologies such as the GUI, the global database, each tool local storage, etc…

The technical requirements are numbered following a "business rule", i.e. TR-XXX-YY, where YY is the sequential number of the technical requirement of tool XXX indicated by the acronym of the tool.

The following sections 3.1 – 3.4 will be organised in four sub-sections:

1. FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS: in this subsection, the transition from functional requirements identified in D2.2 Functional Requirements [8] towards the technical requirements is described as well the connection between them;
2. ARCHITECTURE OF THE TOOL: in this subsection, the main architecture of the tool is described. A diagram for each tool will illustrate the flow of the actions that the tool will carry out when running, the functions that are implemented and the interactions with other modules of the tool;
3. MAIN FUNCTIONS AND MODELS: in this subsection, the main functions are described;
4. DATA REQUIREMENTS: in this subsection, a brief overview of the requirements in terms of data and their internal-to-the-tool organisation into classes.

Following this, sections 3.5 and 3.6 will collect general technical requirements, applicable to all or most of the set of tools, covering:

- INTERFACES/COMPATIBILITY/PORTABILITY: in this section, the possibility of connecting the tool to other software (commercial, open-source, in-house) through the use of interfaces is described, as well as the ability to import inputs and export outputs.
- MAINTENANCE: in this section, the management of extensions and updates in the future is briefly discussed.

3.1 FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS

To obtain the functional requirements, a set of technical functions to be implemented in the stage gate design tool have been defined below. The technical requirements are identified as the actions to be carried out by the Stage Gate design tool to meet the functional requirements.

TABLE 3-1 FUNCTIONAL AND TECHNICAL REQUIREMENTS OF THE STAGE GATE DESIGN TOOL

Functional Requirements
SG-FR1. 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. SG-FR2. Utilise the Deployment and Assessment tools and the Structured Innovation tools to evaluate key parameters associated with sub-systems, devices and arrays. SG-FR3. Compare technologies' evaluation results with user-defined thresholds or standard benchmarks from the ocean energy sector and identify areas of shortfall. SG-FR4. Provide evidence for user's decision-making process through clear presentation and comparison of evaluation results.
Technical Requirements
SG-TR1. Use of database to access project data and load relevant context reference data into Stage Gate local storage SG-TR2. Use of a Stage Gate design tool GUI to allow user interaction with the Stage Gate design tool SG-TR3. Use of Stage Gate design tool GUI to load Stage Gate metrics framework relevant to user context and choices SG-TR4. Use of Stage Gate design tool GUI to display Stage Gate framework information to user including: 4.a Number of stages 4.b Definition of stages by TRL 4.c Stage activities for each stage 4.d Evaluation areas 4.e Metrics for each stage and Evaluation area at relevant levels of complexity SG-TR5. Display stage activities to user, relevant to context choices SG-TR6. Use of GUI to allow user to access more detailed information on each stage activity SG-TR7. Allow the user to select the appropriate stage for stage gate assessment framework, including: 7.a Allow the user to specify which activities have been completed 7.b Allow the user to input justification text on completion of activities 7.c Allow the user to save the justification text in the local storage SG-TR8. Present any outstanding activities for the selected stage to the user SG-TR9. Use of GUI to allow user to enter thresholds for evaluation areas SG-TR10. Present the format options of results to the user: 10.a Allow user to select output options for the Assessment tools 10.b Allow user to modify the format of the presented data SG-TR11. Acquire stage gate assessment results 11.a Request appropriate metric parameters (Simple or complex versions based on the stage gate set-up) from the Deployment and Assessment tool APIs 11.b Receive results from Deployment and assessment tools API SG-TR12. Save all data and results to tool local storage SG-TR13. Present results of stage gate analysis to the user in the form of a report: 13.a Including results from assessment tools 13.b Including assumptions made in the set-up of the stage gate metrics framework 13.c Including any gap analysis from thresholds and results SG-TR14. Allow user to edit the format of the data presented SG-TR15. Display the gaps or shortfalls in results from selected thresholds SG-TR16. Save the project outputs to the Digital Representation using a dedicated interface. SG-TR17. Allow user to select areas to improve to launch Structured Innovation tool for improvement cycle

The technical requirements required to achieve each functional requirement are represented in the table below:

TABLE 3-2 MATRIX OF RELATION BETWEEN FUNCTIONAL AND TECHNICAL REQUIREMENTS

TR \ FR relation matrix		Functional Requirements			
		SG-FR1	SG-FR2	SG-FR3	SG-FR4
Technical Requirements	SG-TR1	x			x
	SG-TR2	x			x
	SG-TR3	x			
	SG-TR4	x			
	SG-TR5	x			
	SG-TR6	x			
	SG-TR7	x			
	SG-TR8	x			x
	SG-TR9	x		x	
	SG-TR10				x
	SG-TR11		x		
	SG-TR12	x			
	SG-TR13	x			x
	SG-TR14				x
	SG-TR15			x	
	SG-TR16	x			
	SG-TR17		x		

The main function of the tool SG-FR1 "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" has the most technical requirements associated with it. For example, the technical requirements which support the definition of a stage gate metrics framework for assessment would be connected to this functional requirement. However, it can be seen in this matrix that all of the technical requirements outlined are necessary in achieving the overall aims of the stage gate design tool.

3.2 ARCHITECTURE OF THE TOOL AND UML DIAGRAM

The main functions of the Stage Gate design tool are shown in Figure 3.1 UML Global architecture diagram for Stage Gate design tool.

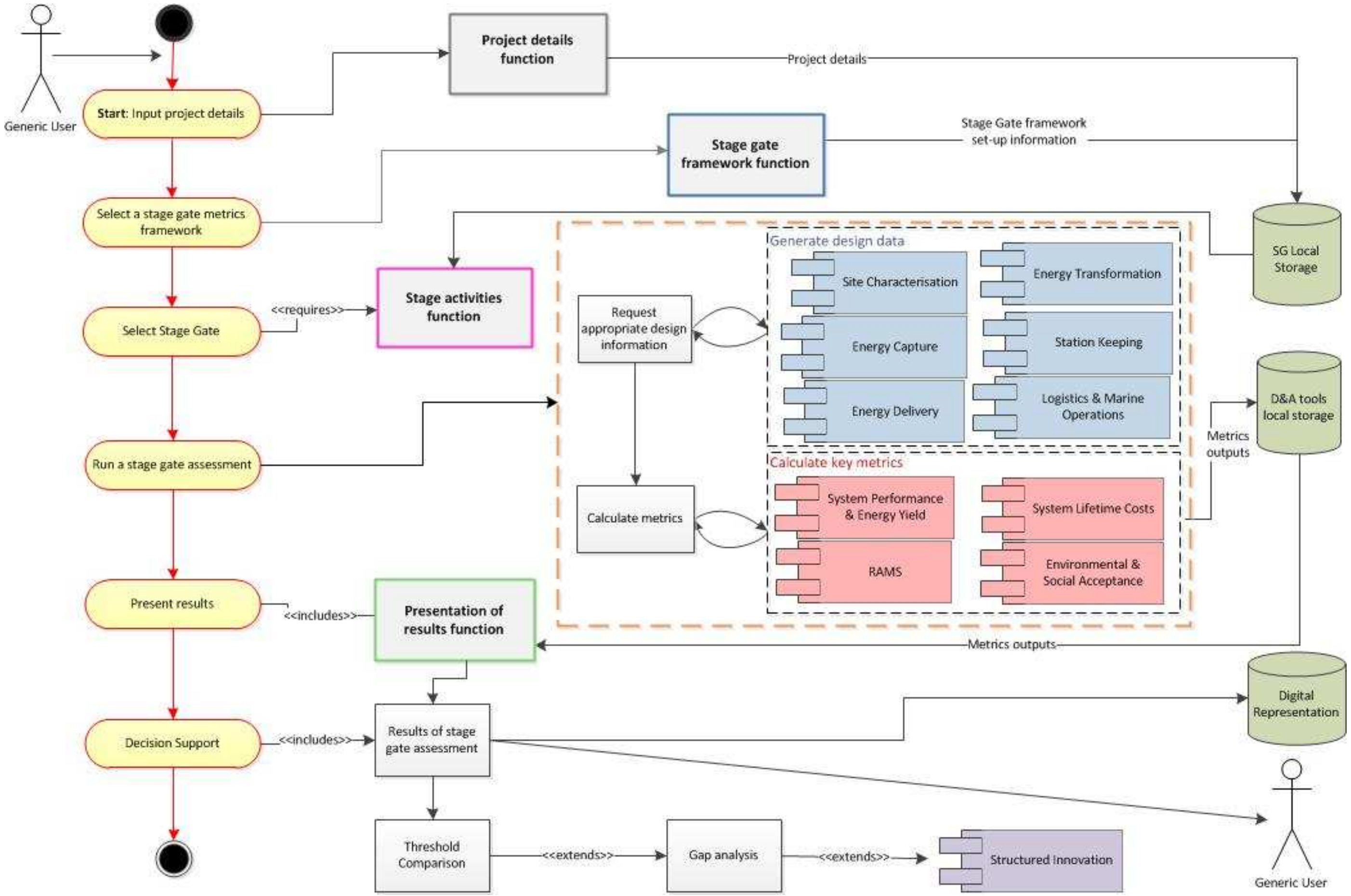

FIGURE 3.1 UML GLOBAL ARCHITECTURE DIAGRAM FOR STAGE GATE DESIGN TOOL

The process of the Stage Gate design tool is outlined on the left side of the UML diagram (Figure 3.1) and is broken up into six steps: Input project details, Select a stage gate metrics framework, Select stage gate, Run a stage gate assessment, Present results and Decision support.

In order for these six steps to run, there are 4 functions which are explained below: 1) Project details 2) Stage Gate framework function 3) Stage activities function and 4) Presentation of results function.

1. Project details: The user will input relevant project details into the DTOceanPlus GUI, which the Stage Gate design tool will access in order to set-up the stage gate assessment. These choices govern what the stage gate metrics framework contains and how it is presented to the user of the Stage Gate design tool. The 'project details' is expanded and depicted in the diagram below. As seen in Figure 3.2, the user will select between wave/ tidal energy for technology type, the aggregation level of sub-system/ device and array and any other context choices to support the assessment.

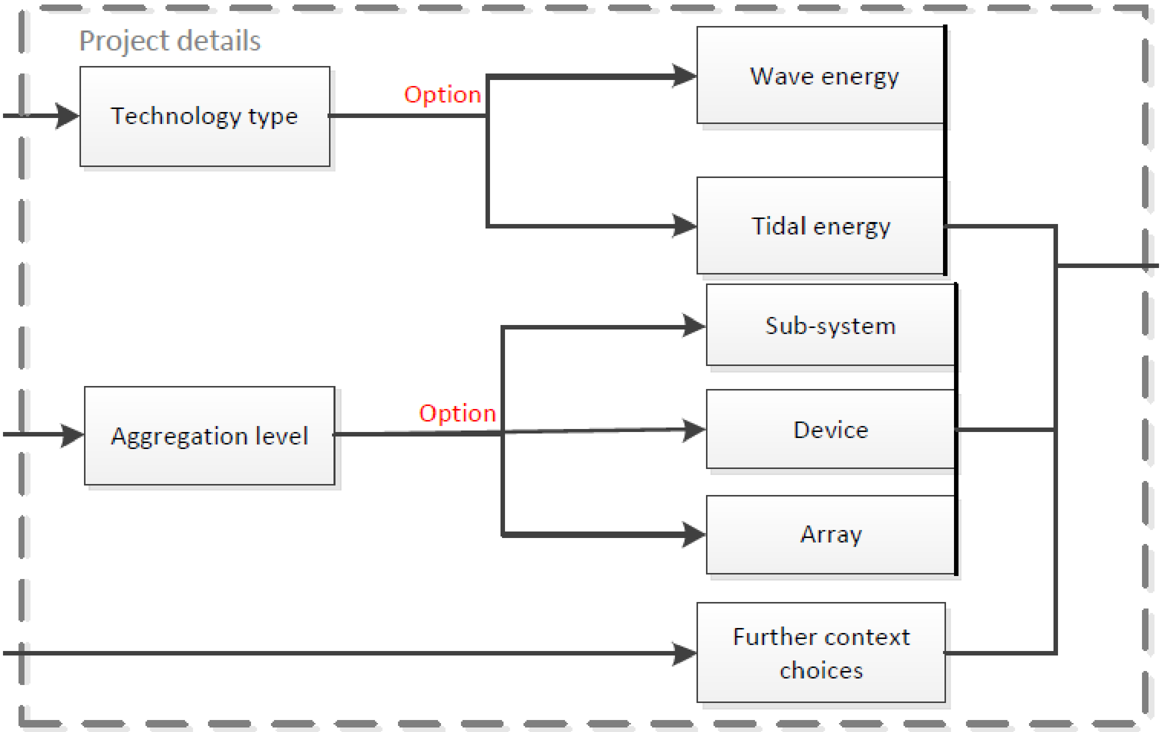

FIGURE 3.2 UML GLOBAL ARCHITECTURE DIAGRAM EXPANDED: PROJECT DETAILS

This information will be stored in the Digital Representation in order to be available to all of the DTOceanPlus tools as required.

2. Stage gate framework function: The next step is in setting up the Stage Gate metrics framework. This will involve interaction with the Stage gate design tool GUI where the user will view and select the default stage gate metrics framework which will be used for the stage assessment. A framework is made up of:

- The number of stages
  - The number of stages the technology or array will pass through during the development process
- Stage activities
  - The research, development and demonstration activity that should be carried out during the prescribed stages
- Evaluation Areas
  - The key areas in which the user wishes to measure the success of ocean energy technology to demonstrate progress and performance
- Metrics
  - The specific parameter(s) used to evaluate how well a technology satisfies the Evaluation Areas

Although a default stage gate metrics framework will be presented, it will be possible for the user to edit the framework which is depicted in Figure 3.3 below.

This information will be stored in the Stage Gate design tool local storage.

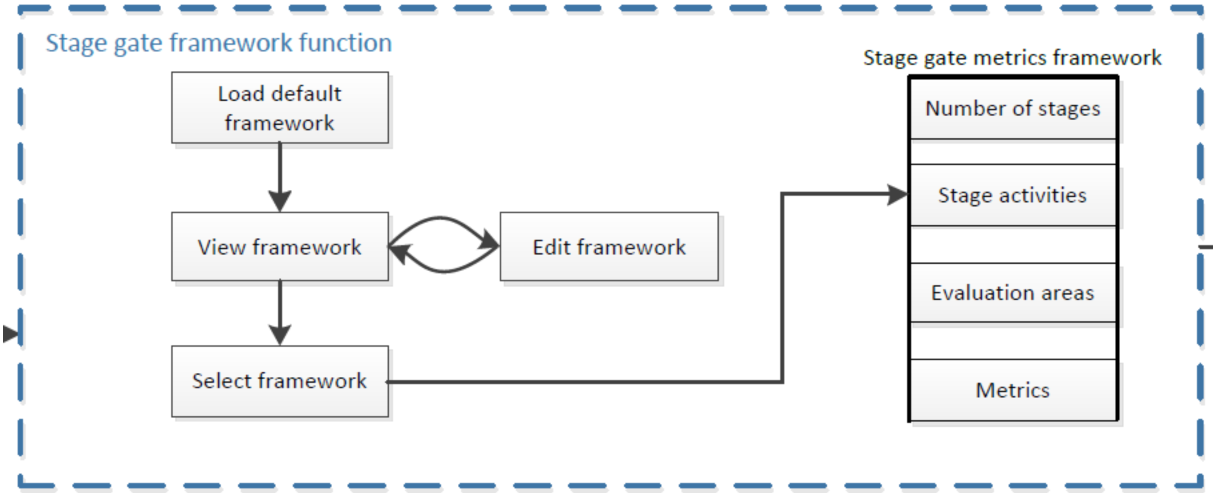

FIGURE 3.3: UML GLOBAL ARCHITECTURE DIAGRAM EXPANDED: STAGE GATE FRAMEWORK FUNCTION

3. **Stage Activities function**: The next step is in selecting the appropriate stage gate for assessment. The Stage gate design tool will present a list of stages and stage activities as seen in Table 3-3.

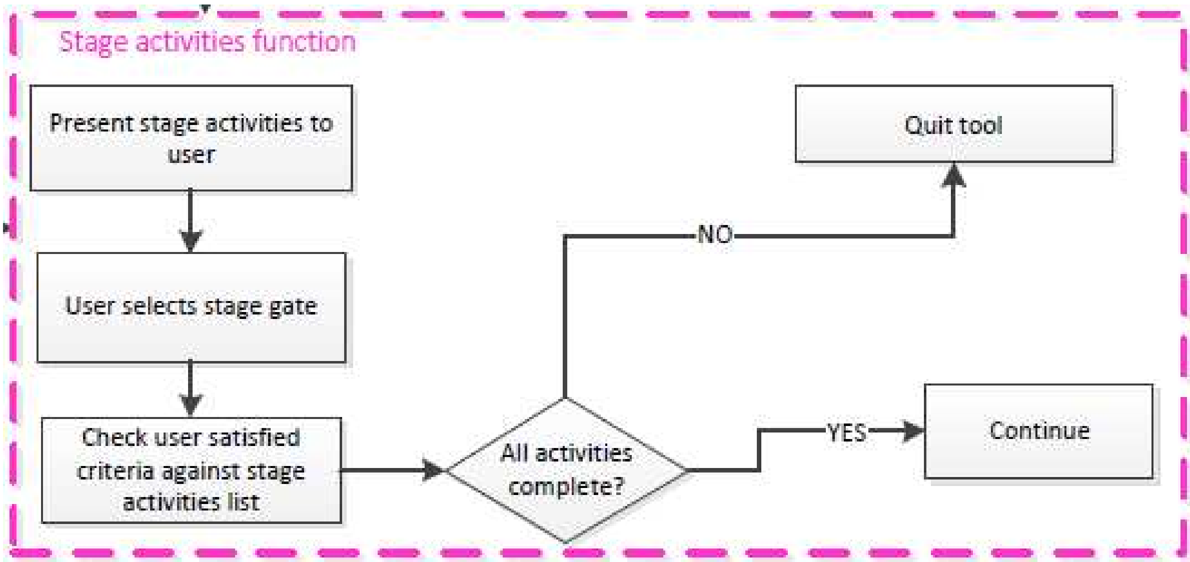

FIGURE 3.4 UML GLOBAL ARCHITECTURE DIAGRAM EXPANDED: STAGE ACTIVITIES FUNCTION

This gives the user the opportunity to decide what stage their technology is ready to be assessed for. Examples of activities are:

- Relevant to engineering design: Complete concept engineering studies for full-scale prototype
- Those relevant to the integration of technology: Recognition of necessary subsystems which comprise the full system
- Or commercial considerations: Project Financial analysis including CAPEX, OPEX and DEVEX.

At this point the user has the option to select the appropriate stage for their technology. A fuller example list of Stage Activities is seen below.

TABLE 3-3 EXAMPLE STAGE ACTIVITIES FOR SUB-SYSTEM, DEVICE AND ARRAY LEVEL

	Stage 0	Stage 1	Stage 2	Stage 3	Stage 4
	Concept creation	Concept development	Design optimisation and feasibility	Manufacturing and operability demonstration in representative environment	Post-Stage 3, commercial scale demonstration
Sub-System	Design/concept meets the needs of the sector and the objectives of the prospective programme. Provides a solution to or improvement on existing state of the art technology challenges.	Concept development of a structural design for a device which incorporates the subsystem.	Complete concept engineering studies for a full-scale prototype, which acts as a vehicle for CAPEX estimation. FEED of the medium-scale sub-system.	Complete engineering assessment and refinement of the manufacturability, installability, maintainability, operability etc. of the system. Complete FEED of at full scale. Demonstrate the optimised technology is a well-developed and refined system.	Input into the structural development of a full-scale energy converter system.
Device	Recognition of necessary subsystems which comprise the full system.	A thorough understanding of the physics of the primary device idea, with knowledge of how device parameters influence hydrodynamic coefficients and in turn, device/PTO dynamic coefficients.	Awareness of all the main structural and wider subsystem elements (main structure, structural bearings, jointing, moorings, PTO), and reliability rates and fatigue loading values from Scale Model Testing & Simulation.	The viability of the device itself is not fundamentally dependant on the success of specific systems or component development programmes.	Systems engineering to optimise interfaces between device prime mover and other device subsystems (e.g. PTO, foundation, ancillaries, etc.) as appropriate.
Array	Assess regional economics including the availability of subsidies and revenue support mechanisms	Project Financial analysis including CAPEX, OPEX and DEVEX	Main contracts tendering and procurement	Risk and financial management studies complete	Risk and financial management studies complete

This information allows the user to then select the stage which is the most appropriate for their technology assessment. The stage activities shown above are examples but not a complete list of the kind of information that the user will be presented with. It's in the user's interest to select the correct stage since they will not have the appropriate data to be assessed at a stage which is too mature for their technology. At this point it is expected that if the user would like to save their study and come back to it at another point then that will be possible – as it's likely that the level of information presented may result in the need to take some time to make an informed decision.

4. Presentation of Results function: The final step is deciding how to display the results of a stage gate assessment in the most relevant way.

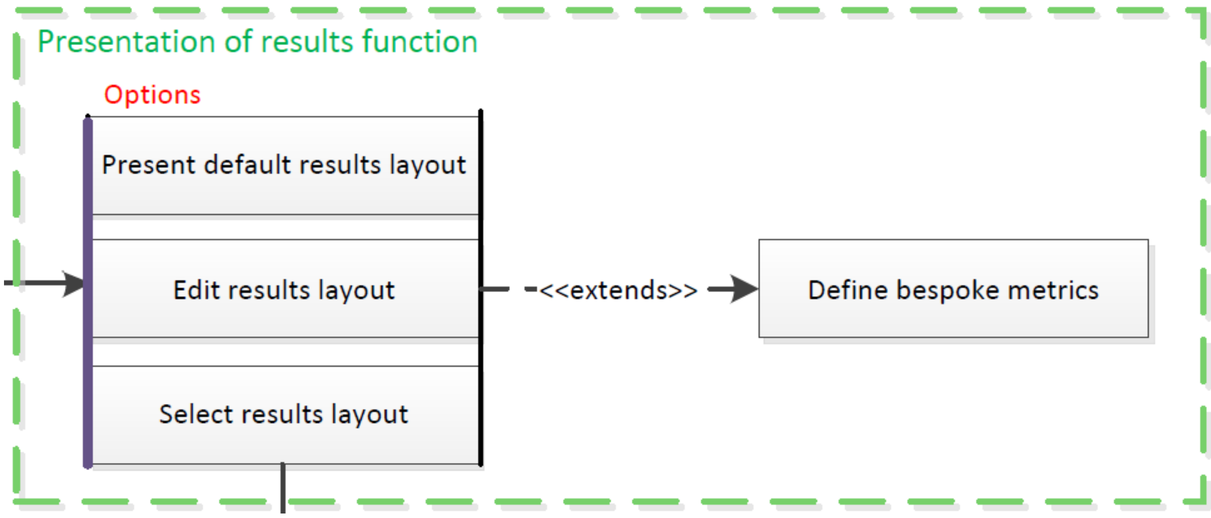

FIGURE 3.5 UML GLOBAL ARCHITECTURE DIAGRAM EXPANDED: PRESENTATION OF RESULTS FUNCTION

An example of the types of presentation format the user could select from is shown below. From top left hand side and going clockwise 1) A summary of the stage gate assessment 2) Performance data as displayed in a scatter diagram 3) An overall summary of all the key metrics in a spider chart 4) A particular metric performance tracking

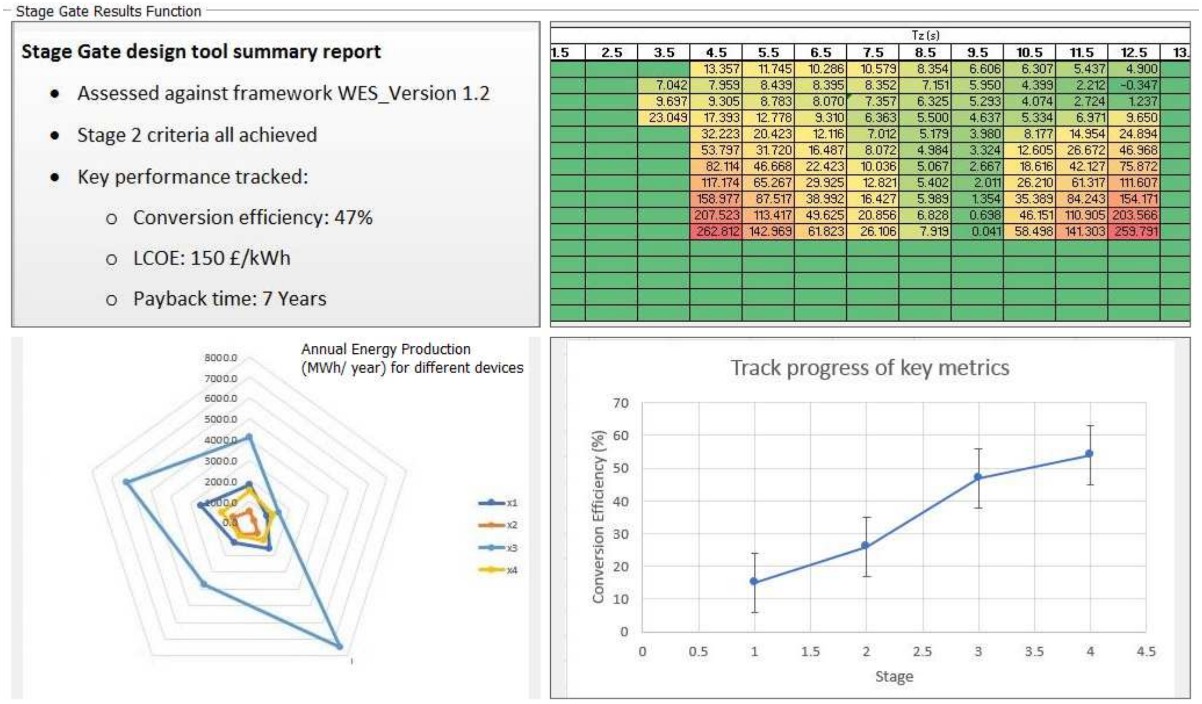

FIGURE 3.6 EXAMPLES OF TYPES OF PRESENTATION FORMAT FOR THE STAGE GATE DESIGN TOOL

The examples above show some of the ways that information can be presented to the user of the Stage Gate design tool:

- A summary of the stage gate assessment
- Performance data as displayed in a scatter diagram
- An overall summary of all the key metrics in a spider chart
- A particular metric and how it's changed as the user has progressed through the stages

3.3 MAIN FUNCTIONS AND MODELS

From the User Groups consultation, all user groups had at least half of respondents say they were either 'likely' or 'very likely' to use the Stage Gate design tool from the four groups: Funders and Investors, Innovators and Developers, Project developers and Policy and Regulators [16] [17].

Examples of the motivation of each of these four groups using the stage gate design tool is seen in the diagram below. Some user groups have crossover, for example Project Developers may be looking to both assess an array and track the progress of one key metric over time.

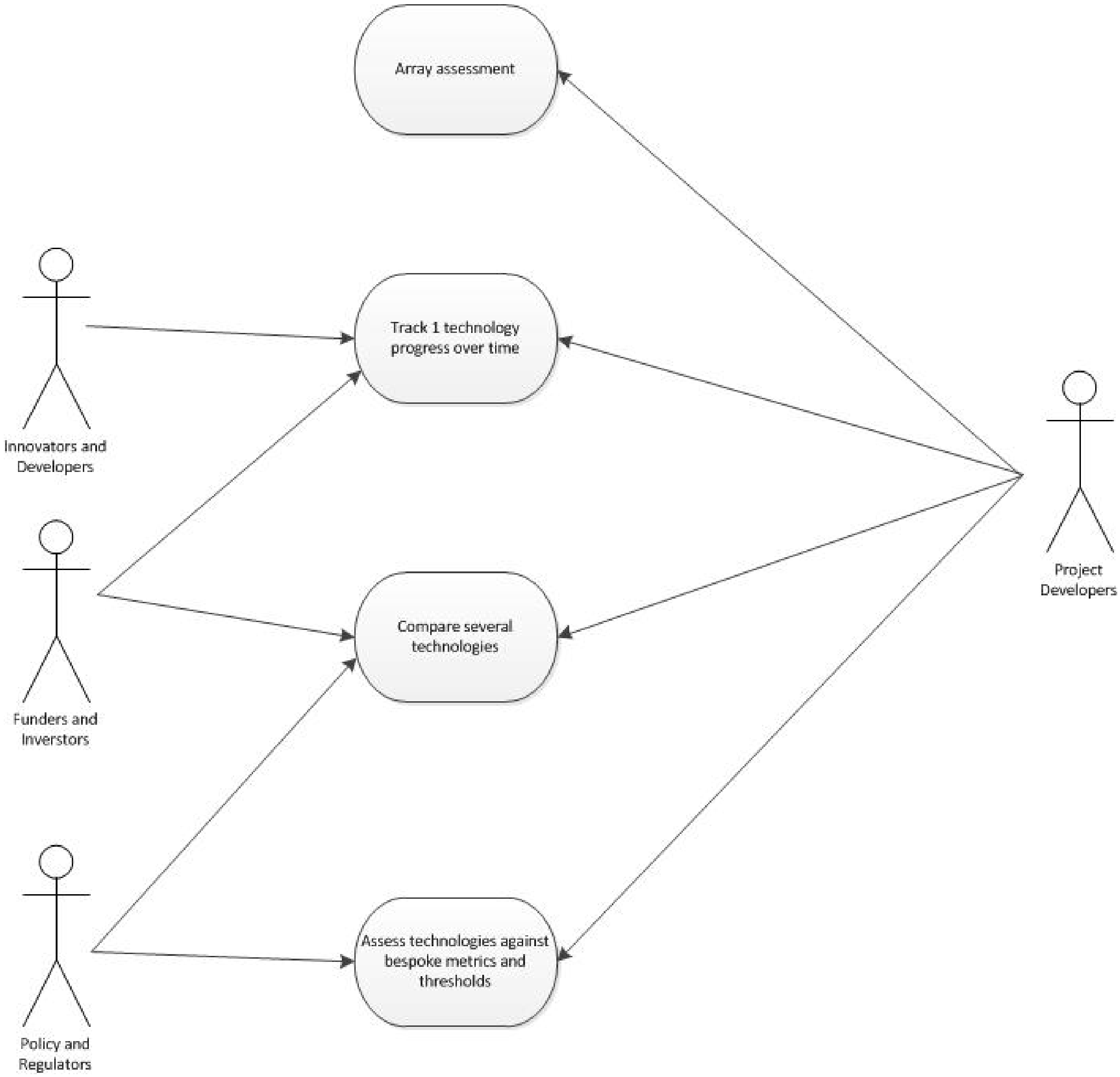

FIGURE 3.7 STAGE GATE DESIGN TOOL USE CASE DIAGRAM: HIGHLIGHTING DIFFERENT USE CASES FROM FOUR MAIN USERS OF THE TOOLS

The remaining use of the Stage Gate design tool is the same for all four user groups, and this is seen in the Use Case diagram below for a 'generic user'.

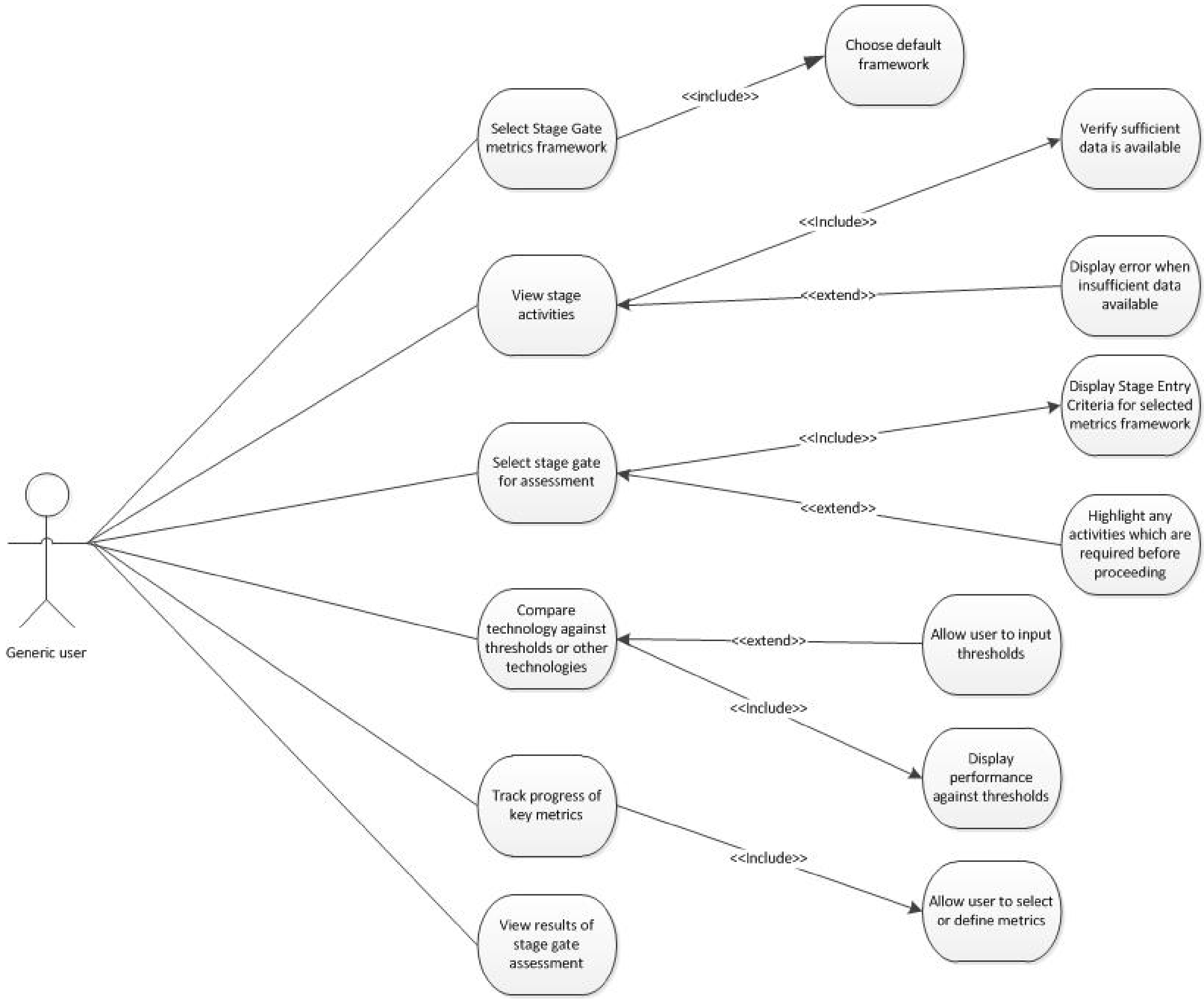

FIGURE 3.8 STAGE GATE DESIGN TOOL USE CASE DIAGRAM FOR GENERIC USER

The stage gate design tool has some flexibility in the set-up so that users can define their own metrics, thresholds and presentation of results. For this reason, the use cases are similar whilst the motivation for using the tool may differ.

3.4 DATA REQUIREMENTS

The data which is processed in the Stage gate design tool is broken up into:

- Stage Gate metrics framework
  - Containing a list of Stage Activities
    - Including a list of Stages and what activities must have been completed to be eligible to be assessed against that stage
      - Each stage has several possible Metrics associated as proposed by the Evaluation areas

- Evaluation areas
  - Includes a list of possible Metrics
    - With user defined thresholds for each metric

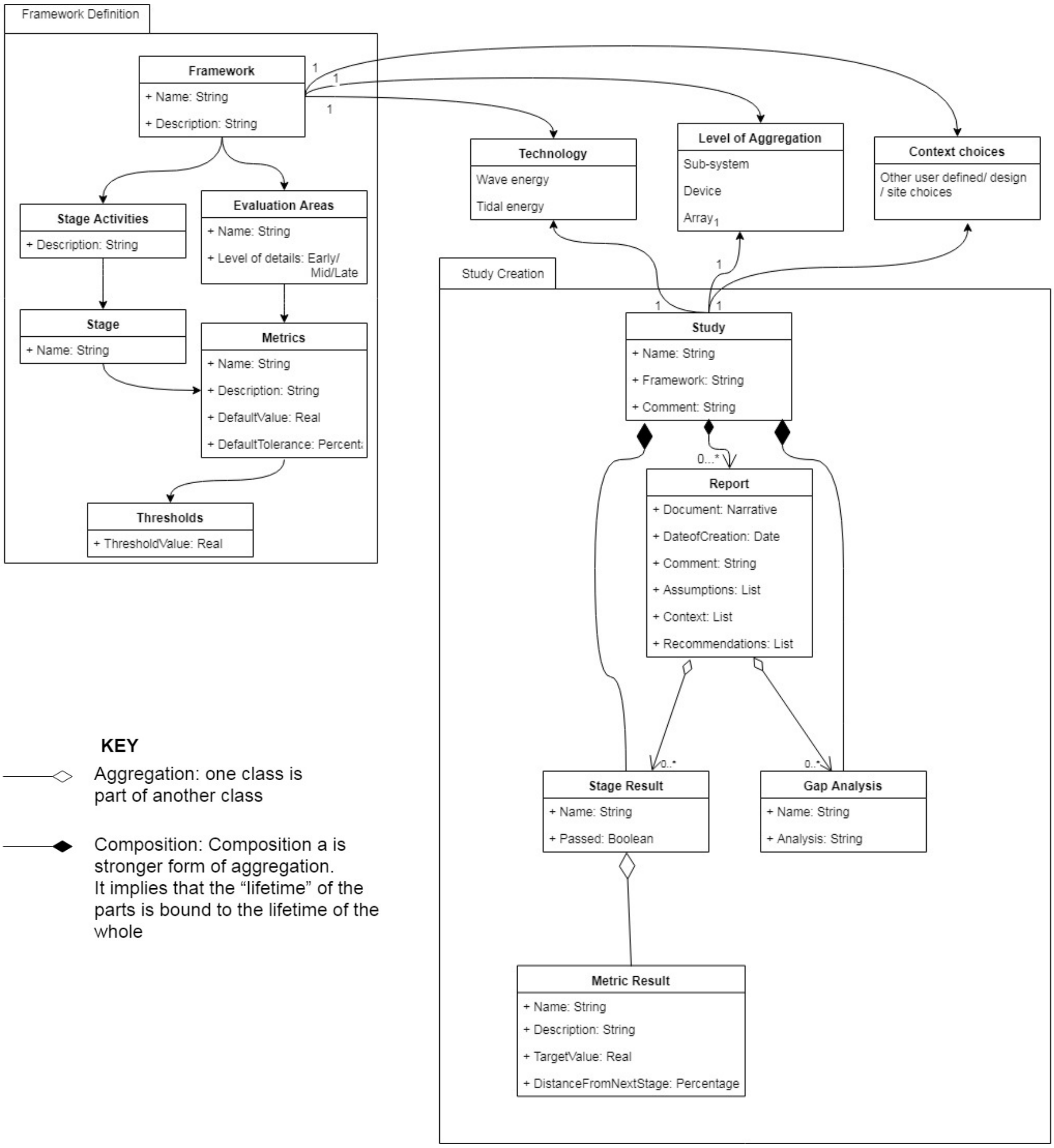

FIGURE 3.9 STAGE GATE DESIGN TOOL CLASS DIAGRAM

3.5 INTERFACES, COMPATIBILITY AND PORTABILITY

Interfaces are expected indirectly through external, third-party tools being used in place of specific modules of the Deployment and Assessment design tools. This may include interfaces of the Stage Gate design tool with external and/or commercial software and where possible, the Stage Gate design tool will be designed to support this.

Export compatibility will be required to support export of Stage Gate design tool results and reports. This will require compatibility with PDF, HTML formats and software platforms.

The Stage Gate design tool fundamentally relies on the evaluation of key metrics by the DTOceanPlus Deployment and Assessment design tools, however, it should accept metrics data evaluated by third party tools in accordance with the compatibility and portability of these individual tools in their own right. It is expected that such "substitution" of a DTOceanPlus for a third-party tool would be managed by that tool's API, leaving the Stage Gate design tool's request for a metric parameter satisfied with no change in functionality within the Stage Gate design tool GUI.

The Stage Gate design tool will use presentation formats and drivers from the Deployment and Assessment design tools and should therefore achieve graphical user interface compatibility with the tools in question.

For integration with the platform, the assessment tools, other deployments tools and the database, see Section 4.

3.6 MAINTENANCE

Following the development and delivery of the DTOceanPlus suite of tools, the software maintenance expected with respect to the Stage Gate design tool are:

- Reference data associated with the definition of a Stage Gate assessment context e.g. supporting the ability of a user to assess a subsystem in the context of an example device in an example array, enabling assessment of project level metrics such as LCOE
- Stage Gate Metrics Framework, including the default content of:
  - Number of stages
  - Definition of stages by TRL
  - Stage Activities for each stage
  - Evaluation areas
  - Metrics for each stage and Evaluation area
- Default values are not expected to be created for thresholds, however, this could change in the future and so this data should also be maintained.

4. TECHNICAL SPECIFICATIONS FOR THE INTEGRATION OF THE STAGE GATE DESIGN TOOL IN DTOCEANPLUS TOOLSET

4.1 INTEGRATION WITH THE UNDERLYING PLATFORM AND DIGITAL REPRESENTATION

The stage gate design tool interacts with all of the tools in the DTOceanPlus suite. The communication is summarised as:

- The Deployment tools are used to provide design information based on the technology, aggregation level and context choices made by the user
- The Assessment tools take all of this information and calculate key metrics which are fed back in to the stage gate design tool
- The Structured Innovation tool is triggered when the results of the stage gate assessment show a divergence from the thresholds as set by the user or a gap in one of the Evaluation Areas when all metrics results are presented together

The interaction between the stage gate design tool and the GUI, Deployment, Assessment and the Structured Innovation tools can be seen below.

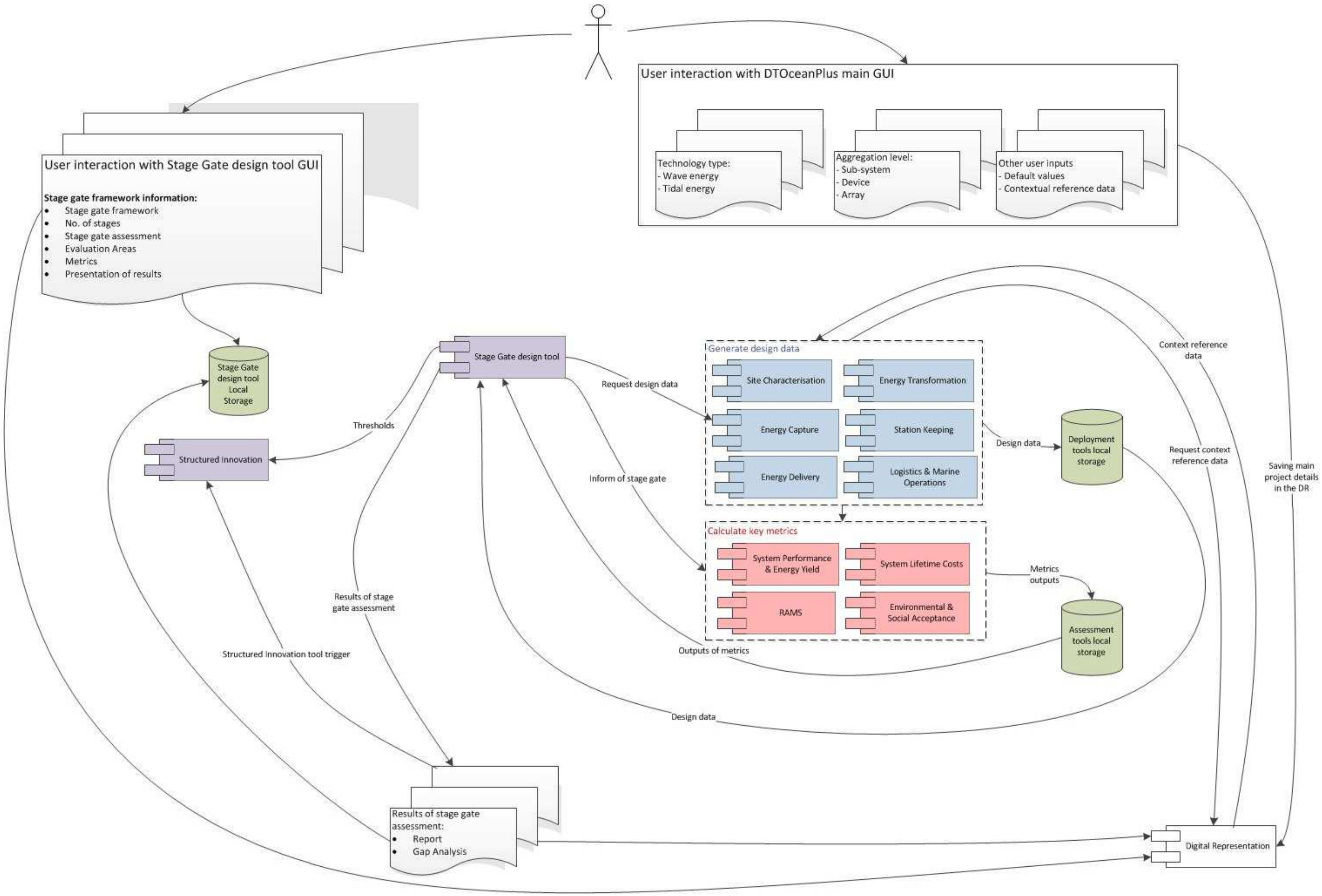

FIGURE 4.1 INTERACTION OF THE STAGE GATE DESIGN TOOL AND THE GUI

The user and the SG design tool GUI: The user inputs the relevant data in the Stage Gate design tool which is necessary for the tool to run. This includes the choices in the set-up of the stage gate metrics framework, i.e.:

- Number of stages
- Definition of stages by TRL
- Stage Activities for each stage
- Evaluation areas
- Metrics for each stage and Evaluation area

This information is then stored in the Stage Gate design tool Local Storage.

Interaction with the Deployment and Assessment tools: The stage gate design tool interacts with the Deployment tools to request design data or to run an assessment to output key metrics. The outputs of the deployment and assessment tools are stored in their local storage and then accessible by the stage gate design tool when required. If the deployment and assessment tools require further information on context reference data to run, they can access this from the Digital Representation.

Data for the Digital Representation: As can be seen in the diagram, the information and data which is being passed to the Digital Representation is:

- The stage gate metrics framework set-up. This means that the user would be able to save this set-up as a "version" and then run the same set-up again at a different time.
- Results from the stage gate assessment. This means the output which would be in the form of a report can be produced and displayed in a standardised format, enabling comparison between stage gate assessments.
- Technology information such as wave/tidal energy, aggregation level (sub-system, device or array) and any context reference data.

4.2 INTEGRATION WITH THE DATABASE

The Global Database is a centralised storage for common references of the application. It contains a list of catalogues that will be accessible by any module. The Stage Gate design tool will use the Catalogues Database to propose to the user the list of possible metrics and assessments.

As can be seen in Figure 4.1, the Stage Gate design tool will have its own GUI and local storage for data and information which is specific to the tool itself. This information includes the definition of the Stage Gate metrics framework, no. of stages, evaluation areas to be assessed against, metrics etc.

The Stage Gate design tool will access the request design data (from the Deployment tools) or receive the outputs of metrics (from the Assessment tool) using services provided by other tools. Reciprocally, other design tools may access the Stage Gate design tool information using services provided by the Stage Gate design tool. For example, the Structured Innovation tool will request information from the Stage Gate design tool to be informed of areas of improvement for a technology.

Each module can store/persist its data in the format it requires within its local storage, but the way the information is available is given by the definition of the public services.

4.3 INTEGRATION WITH THE DEPLOYMENT TOOLS

The stage gate design tool communicates with the Deployment tools in two ways:

1) Indirectly: When a stage gate assessment is run, the Stage Gate design tool will request metrics from the Assessment tools. In order to compute these assessments of metrics, the Assessment tools will require design information from the Deployment tools. The relevant information will be passed from the Deployment tools to the Assessment tools, which will in turn deliver the relevant metrics back to the Stage gate design tool

2) Directly: When a user has defined bespoke metrics, there will be some specific design information which is required from the Deployment tools. An example of this is if a user required the metric of 'Annual absorbed energy per wetted surface area (MWh/m^2)' then some design information is needed from the Deployment tools, (Wetted surface area, m^2), and some assessment information is required from the assessment tools (Annual absorbed energy, MWh). As required, the Stage Gate design tool will request information to support bespoke metrics, if they're available from the Assessment and Deployment tools.

4.4 INTEGRATION WITH THE ASSESSMENT TOOLS

As described in Section 3.3 above, the Stage Gate design tool interacts with the Assessment tools by requesting metrics to be computed and returned as required, at the appropriate level of complexity.

The assessment tools which compute the key calculations to support the Stage Gate assessment are each outlined in the tables below, displaying:

- The design information which is provided by each of the Deployment tools at the specific level of complexity; Early/ Mid/ Late, and
- The Metrics which are calculated for each of these stages to support the Stage Gate assessment.

This is an ongoing piece of work and as the tools are developed the metrics will evolve and change. The details in the tables below are intended to provide examples of how the available design data changes throughout technology maturity stages and therefore the assessment approaches change.

TABLE 4-1 SYSTEM LIFETIME COSTS: DESIGN INFORMATION AVAILABLE FOR ASSESSMENT AND METRICS TO SUPPORT STAGE GATE ASSESSMENT

Deployment tool for design information	Main parameter to assess	Early	Mid	Late
Outputs of Site Characterisation tool	N/A	Indirectly - the resource information from Site Characterisation informs the Energy Capture tool which affects System Performance and Energy Yield (AEP) and therefore System Lifetime Costs (LCOE).		
Outputs of Energy Capture tool	N/A	Indirectly - the Energy Capture data is collated by System Performance and Energy Yield together with Energy Transformation and Energy Delivery to produce an AEP which is then passed to the Lifetime Costs tool		
Outputs of Energy Transformation tool	Cost of PTO components	Bill of materials from default PTO parts based on catalogue values	Bill of Materials for a specific Power Take-Off design will be generated at this stage. The optimiser can select the best components reducing the global cost of equipment with the appropriate cost function.	Optimised PTO configuration that can include specific user parameters when available with a specific control strategy. The optimiser can be run with the global cost reduction objective.
Outputs of Energy Delivery tool	Electrical infrastructure Bill of Materials	Specific components not identified for energy delivery network. Distances based on proxies, and do not consider installation/protection methods	Typical components used for energy delivery network. Distances based on simplified cable routing, including some information on installation/protection methods	Specific components for energy delivery network selected from catalogue. Distances based on optimal cable routing, including detailed information on installation/protection methods
Outputs of Station Keeping tool	Station keeping Bill of Materials	Basic station keeping design based on drop down list of standard components for WEC/TEC rating (e.g. based on a lookup table of standardised moorings and foundations designs) Not including umbilical and not site specific	Station keeping design informed from numerical model and consideration of extreme loads. Non-standardised components included (i.e. those which are out with the lookup table of standardised moorings and foundations designs) Not optimised for minimisation of LCOE	A technically feasible station keeping design which minimises the LCOE of the project.

Deployment tool for design information	Main parameter to assess	Early	Mid	Late
Outputs of Logistics and Marine Operations tool	Vessel, port and equipment costs. Scheduling of costs throughout project lifetime	Typical vessel combinations (e.g. installation vessel + support vessel+ ROV), as well as vessel and equipment costs for a simplified/assumed operation plan.	O&M plan will have vessel, equipment and port costs built in to produce total O&M cost for lifetime of project. This includes use of default values.	Full and detailed O&M plan will give O&M costs broken down per year of project life
Metrics required for Stage Gate design tool	**Affordability**	**Cost proxy e.g. Installed capacity (MW)/ Weight (tonnes)**	**LCOE (€/kWh)**	**LCOE (€/kWh)**
	Installability	**Cost to install score (low, med, high)**	**Cost of installation (€)**	**Cost of installation (€)**
	Manufacturability	**Cost to manufacture (€)**	**Cost to manufacture (€)**	**Cost to manufacture (€)**
	Maintainability	**Cost of maintenance (€)**	**Cost of maintenance (€)**	**Cost of maintenance (€)**

TABLE 4-2 RAMS TOOLS: DESIGN INFORMATION AVAILABLE FOR ASSESSMENT AND METRICS TO SUPPORT STAGE GATE ASSESSMENT

Deployment tool for design information	Main parameter to assess	Early	Mid	Late
Outputs of Site Characterisation tool to be passed to Assessment tools	Site specific information	For generic site chosen (Low/ Med/ High energy) the information which would be provided from the database is: Accessibility of site, availability of vessels and resource data to inform availability of weather windows *This may go directly to Logistics and Marine Operations first*	For a specific site chosen, the information provided is: Accessibility of site, availability of different types of vessels and resource data to inform availability of weather windows. *This may go directly to Logistics and Marine Operations first*	

Deployment tool for design information	Main parameter to assess	Early	Mid	Late
Outputs of Energy Capture tool to be passed to Assessment tools	Hydrodynamic loads *This may come from the energy transformation and from the station keeping*	Information on hydrodynamic loads to inform reliability and survivability assessments	Information on hydrodynamic loads to inform reliability and survivability assessments	Information on hydrodynamic loads to inform reliability and survivability assessments
Outputs of Energy Transformation tool to be passed to Assessment tools	Statistical Distribution of PTO loads and Bill of Materials for PTO	Provide default failure rates when available in the catalogue and rough estimate of the distribution of the PTO loads under basic control strategy	As the PTO components are more detailed so are their operation ranges and working loads. The optimiser can include a cost function to improve the reliability criteria.	If all components have sufficient failure rate data for FMEA, the load distribution along the project life can be calculated with specific components under a specific and more advanced control strategy.
Outputs of Energy Delivery tool to be passed to Assessment tools	Electrical infrastructure Bill of Materials	Default values of failure rates for generic components	Typical components from the catalogue have associated default values of failure rates. Network hierarchy based on simplified network	Specific components selected from catalogue, with associated failure rate data adjusted for installation/protection method. Network hierarchy based on optimised network.
Outputs of Station Keeping tool to be passed to Assessment tools	Station keeping Bill of Materials	N/A	Where possible, components from the catalogue and associated Bill of Materials have default values of failure rates.	Where possible, components have sufficient failure rate data for FMEA of station keeping design.

Deployment tool for design information	Main parameter to assess	Early	Mid	Late
Outputs of Logistics and Marine Operations tool to be passed to Assessment tools	O&M plan	Basic O&M schedule for RAMS to calculate Availability (%) of project over lifetime	Detailed O&M plan for both planned and unplanned maintenance broken down per year of project life	Full O&M plan for specific site for both planned and unplanned maintenance using FMEA, broken down per year of project life
Metrics required for Stage Gate design tool	**Reliability**	**Mean Time to Failure (MTTF) in hours**	**Mean Time to Failure (MTTF) in hours**	**Mean Time to Failure (MTTF) in hours**
	Availability	**Availability (%)**	**Availability (%)**	**Availability (%)**
	Maintainability	**Mean time to repair score (low, med, high)**	**Mean time to repair (hours)**	**Mean time to repair (hours)**
	Survivability	**Probability of structural irreparable failure**	**Probability of structural irreparable failure**	**Probability of structural irreparable failure**

TABLE 4-3 SYSTEM PERFORMANCE AND ENERGY YIELD DESIGN INFORMATION AVAILABLE FOR ASSESSMENT AND METRICS TO SUPPORT STAGE GATE ASSESSMENT

Deployment tool for design information	Main parameter to assess	Early	Mid	Late
Outputs of Site Characterisation tool	Resource data for Performance and Energy Yield Tools	Class of site selected from a dropdown list (Low/ Medium/ High energy site) with a power matrix or current velocity profile provided from the catalogue/ database At this stage the technology assessment is likely to be for a generic site	Site specific data provided so energy available at site can be calculated. This will include bathymetry, soil data, wave scatter diagram, wind speed, current velocity profiles, extreme wave or current states Some default values generated when data is missing	Site specific data provided so energy available at site can be calculated. This will include bathymetry, soil data, wind speed, wind direction, standard deviation of wind speed, current velocity profiles, wave statistics, water level statistics, current statistics, extreme wave or current states, power matrices for specific locations and turbulence data. Some default values generated when data is missing

Deployment tool for design information	Main parameter to assess	Early	Mid	Late
Outputs of Energy Capture tool	Hydrodynamic Energy Capture	Average absorbed mechanical energy captured for the specified site	• Quantification of the absorbed energy at farm and device level • Captured Energy per sea state including direction (for wave energy) or current velocity profile including direction (for tidal energy) Array q – factor	• Quantification of the absorbed energy at farm and device level • Captured Energy per sea state including direction (for wave energy) or current velocity profile including direction (for tidal energy) Array q – factor
Outputs of Energy Transformation tool	PTO components efficiency	• Components efficiency from default values taken from the catalogue • Power production per device, breakdown per conversion step	• Detailed calculated efficiencies for specific components: include deeper PTO optimisation function with more accurate components efficiencies • Power performance same as early but more accurate	A finer calculation of the components efficiencies and power production outputs including optimised PTO components that can include specific user functions and parameters (i.e. test a specific developers PTO)
Outputs of Energy Delivery tool	Total electrical efficiency Grid compliance and power factor	Annual energy production based on rated power of device/ array only, with assumed losses grid compliance and power factor ignored	Electrical efficiency and annual energy production calculated for simplified network using average resource. Simplified grid compliance assessment and average power factor	Electrical efficiency and annual energy production of project is calculated for optimised electrical infrastructure layout including specific components selected from catalogue, using detailed resource data. Detailed grid compliance assessment and power factor used for optimisation

Deployment tool for design information	Main parameter to assess	Early	Mid	Late
Outputs of Station Keeping tool	Effect of dynamic response of moorings and foundations on energy capture	N/A	Indirectly – Through the Energy Capture tool the effect of station keeping solution on energy capture informed from numerical model. Design not optimised to maximise energy capture	
Outputs of Logistics and Marine Operations tool	Downtime	Simplified downtime calculation based on Basic O&M schedules and reliability data for assumed subsystems estimated by the RAMS public methods	Simplified downtime calculation based on O&M plan, simplified activity Operating Limiting Conditions (OLCs), weather windows, and considering subsystem and component reliability data calculated by the RAMS public methods.	Complete downtime calculation based on detailed O&M schedules, considering each activity and operation limits, weather windows, and subsystem and component reliability data/MTTF calculated by the RAMS public methods
Metrics required for Stage Gate design tool	**Energy Capture**	**Hydrodynamic energy capture (kWh/year) from System Performance and Energy Yield**	**Hydrodynamic energy capture (kWh/year)**	**Hydrodynamic energy capture (kWh/year)**
		AEP (kWh/year)	**AEP (kWh/year)**	**AEP (kWh/year)**
	Energy Conversion	**Conversion efficiency (%) Hydrodynamic - Mechanical**	**Conversion efficiency (%)**	**Conversion efficiency (%)**
		Conversion efficiency (%) Mechanical to grid compliant	**Conversion efficiency (%)**	**Conversion efficiency (%)**

TABLE 4-4 ENVIRONMENTAL AND SOCIAL ACCEPTANCE DESIGN INFORMATION AVAILABLE FOR ASSESSMENT AND METRICS TO SUPPORT STAGE GATE ASSESSMENT

Deployment tool for design information	Main parameter to assess	Early	Mid	Late
Outputs of Site Characterisation tool	Information on the site	N/A	Each site will have associated information which is required e.g.Local vessel routes	
Outputs of Energy Capture tool	Resource reduction	N/A	Resource Reduction	Resource Reduction
Outputs of Energy Transformation tool	Environmental and social impacts	Default PTO components provide some details on the environmental impact. Mainly impacts have rough estimated based on the type of PTO technology.	Components are becoming more specific and the impacts are more detailed. Also the working conditions are known and can have an effect on the impact (i.e. failure of certain component producing liquid leakage)	The environmental and social impacts are better known especially for a novel PTO.
Outputs of Energy Delivery tool	Bill of Materials and project details	N/A	Typical components from the catalogue have associated information on the materials, weights, and manufacturing process (where available) for the Environmental and Social tools to assess environmental impact of components	Specific components selected from the catalogue have associated information on the materials, weights, and manufacturing process (where available) for the Environmental and Social tools to assess environmental impact of components. Project details such as depth of cables and footprint of electrical infrastructure are available for the Environmental and Social tools to assess overall impact of electrical infrastructure.

Deployment tool for design information	Main parameter to assess	Early	Mid	Late
Outputs of Station Keeping tool	Bill of Materials and project details	Components from the catalogue have associated information on the manufacturing process for the Environmental and Social tools to assess environmental impact of components	Components from the catalogue have associated information on the manufacturing process for the Environmental and Social tools to assess environmental impact of components. Project details such as depth of cables and footprint of electrical infrastructure are available for the Environmental and Social tools to assess overall impact of electrical infrastructure.	
Outputs of Logistics and Marine Operations tool	Environmental parameters related to the operations	Fuel consumption based on basic Installation and O&M activities to estimate CO_2 emissions. *If not available use of default site location to estimate transit fuel consumption.* *Number of vessels for collision risk calculation.*	Logistical outputs/parameters that have an impact on the environmental/social acceptance of a project (e.g. distance to port). Total vessel fuel consumption based on distance to port and O&M plans per year or the vessel size/power, the number of hours of intervention in sea etc. Vessel routes and number of vessels to calculate collision risk.	
Metrics required for Stage Gate design tool	Environmental impact	Environmental Impact Assessment (EIA)	Environmental Impact Assessment (EIA)	Environmental Impact Assessment (EIA)
		Carbon footprint (CO_2kg/MW)	Carbon footprint (CO_2kg/MW)	Carbon footprint (CO_2kg/MW)
	Social impact	No. of jobs/ MW	No. of jobs/ MW	No. of jobs/ MW
		Cost of consenting (£/MW)	Cost of consenting (£/MW)	Cost of consenting (£/MW)

TABLE 4-5 TABLE OF METRICS: SUMMARY OF THE KEY METRICS PASSED FROM THE ASSESSMENT TOOLS TO THE STAGE GATE DESIGN TOOL

Evaluation Area	Assessment tool	Metric		
		Early stage	Mid stage	Late stage
Affordability	System Lifetime Costs	Cost proxy e.g. Installed capacity (MW)/ Weight (tonnes)	LCOE (€/kWh)	LCOE (€/kWh)
Installability	System Lifetime Costs	Cost to install score (low, med, high)	Cost of installation (€)	Cost of installation (€)
Manufacturability	System Lifetime Costs	Cost to manufacture (€)	Cost to manufacture (€)	Cost to manufacture (€)
Reliability	RAMS	Mean Time to Failure (MTTF) in hours	Mean Time to Failure (MTTF) in hours	Mean Time to Failure (MTTF) in hours
Availability	RAMS	Availability (%)	Availability (%)	Availability (%)
Maintainability	RAMS	Mean time to repair score (low, med, high)	Mean time to repair (hours)	Mean time to repair (hours)
	System Lifetime Costs	Cost of maintenance (€)	Cost of maintenance (€)	Cost of maintenance (€)
Survivability	RAMS	Probability of structural irreparable failure	Probability of structural irreparable failure	Probability of structural irreparable failure
Energy Capture	System Performance and Energy Yield	Hydrodynamic energy capture (kWh/year)	Hydrodynamic energy capture (kWh/year)	Hydrodynamic energy capture (kWh/year)
	System Performance and Energy Yield	AEP (kWh/year)	AEP (kWh/year)	AEP (kWh/year)
Energy Conversion	System Performance and Energy Yield	Conversion efficiency (%) Hydrodynamic - Mechanical	Conversion efficiency (%) Hydrodynamic - Mechanical	Conversion efficiency (%) Hydrodynamic - Mechanical
	System Performance and Energy Yield	Conversion efficiency (%) Mechanical to grid compliant	Conversion efficiency (%) Mechanical to grid compliant	Conversion efficiency (%) Mechanical to grid compliant
Acceptability	Environmental impact	EIA	EIA	EIA
		Carbon footprint (CO_2kg/MW)	Carbon footprint (CO_2kg/MW)	Carbon footprint (CO_2kg/MW)
	Social impact	No. of jobs/ MW	No. of jobs/ MW	No. of jobs/ MW
		Cost of consenting (€/MW)	Cost of consenting (€/MW)	Cost of consenting (€/MW)

As can be seen in the table, an example of a metric which doesn't change throughout all stages of technology development is Availability (%) as part of the RAMS tools – however how the metric is calculated will differ as the amount of data available changes, as can be seen in Section 3.3 Integration with the Deployment Tools.

There will be the option for users to define bespoke metrics which are more appropriate and relevant for their technology. The user will be somewhat limited in the relative metrics which can be combined for their own interests and needs since there is a reliance on the outputs that the Assessment tools provide. An example of some metrics which could be put together at the users' request are seen in the table below, which are combinations of the outputs of the Deployment and Assessment tools. These may change and adapt as the project continues, but are intended to provide examples of metrics which can be put together from the outputs of the Deployment and Assessment tools.

TABLE 4-6 EXAMPLES OF BESPOKE METRICS

Bespoke metric	Units	Information needed from user	Data needed from Deployment or Assessment tools
Capture width ratio (CWR)	Non-dimensional	Characteristic length (m)	Power capture (kW)
Power to Weight Ratio (PWR)	kW/kg	n/a	Power capture (kW), Mass of sub-system or device (kg)
Annual absorbed energy per wetted surface area	MWh/m²	Wetted surface area (m²)	Annual absorbed energy (MWh)

The purpose of the bespoke metrics is to allow the users to combine existing information they have gathered as outputs of their stage gate assessment in the most appropriate and useful way. This will allow companies to track the metrics that are most important to their technology. The table above serves as an example only and is not the final list.

4.5 INTEGRATION WITH THE STRUCTURED INNOVATION TOOL

The Structured Innovation design tool will have two main objectives:

- Concept creation: At very early stage: to provoke innovation by scanning the design space, identifying potential innovative concepts, and by ensuring every proposed concept is assessed and has objective scrutiny
- Improvement cycles: At later stages of product development to help address emergent challenges, and sometimes to reappraise and redesign components or systems to overcome such challenges.

The Stage Gate design tool will interact with the Structured Innovation tool in a number of ways:

- By triggering improvement cycles: When the result of the stage gate assessment highlights a weakness in a technology or areas where more R&D activity should be focused, this will highlight areas where the developer can use the Structured Innovation design tools to assist them to identify improvement opportunities i.e. This is the Structured Innovation "improvement cycles". This will be seen by comparing metric thresholds to the results of the Deployment and Assessment tools and will then provide a starting point for the Structured Innovation tool to guide the user in improving their design.

- Where available, the Stage Gate design tool will provide thresholds for metrics to the Structured Innovation tools. These may come from benchmarking the state-of-the-art which will be useful for the users of the tools to create their Target values as part of the Structured Innovation design tool.
- Additionally, 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.

4.6 DESCRIPTION OF THE MODULE GRAPHICAL USER INTERFACE

The user will interact with the Stage Gate design tool GUI to be guided in the stage gate assessment. Below is a mock-up of the Stage Gate design tool GUI, with the steps in the user experience listed on the left-hand side (as aligns with the global architecture UML diagram).

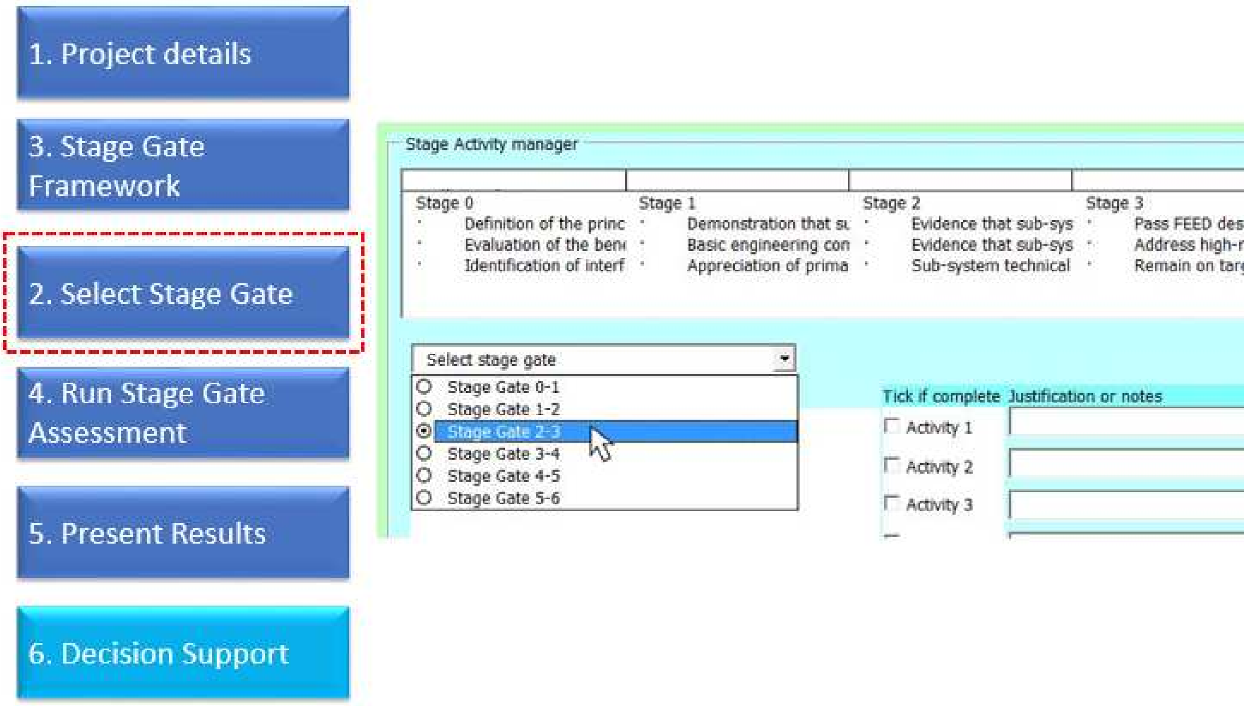

FIGURE 4.2 STAGE GATE DESIGN TOOL GRAPHICAL USER INTERFACE MOCK-UP: SELECTING A STAGE GATE

In order to select the appropriate stage gate for assessment, the user is presented with the stage activities which must have been completed to be ready for assessment. At this point the user may want to save their study and come back to it. It's expected that there will be a high-level overview of activities and then more details if required.

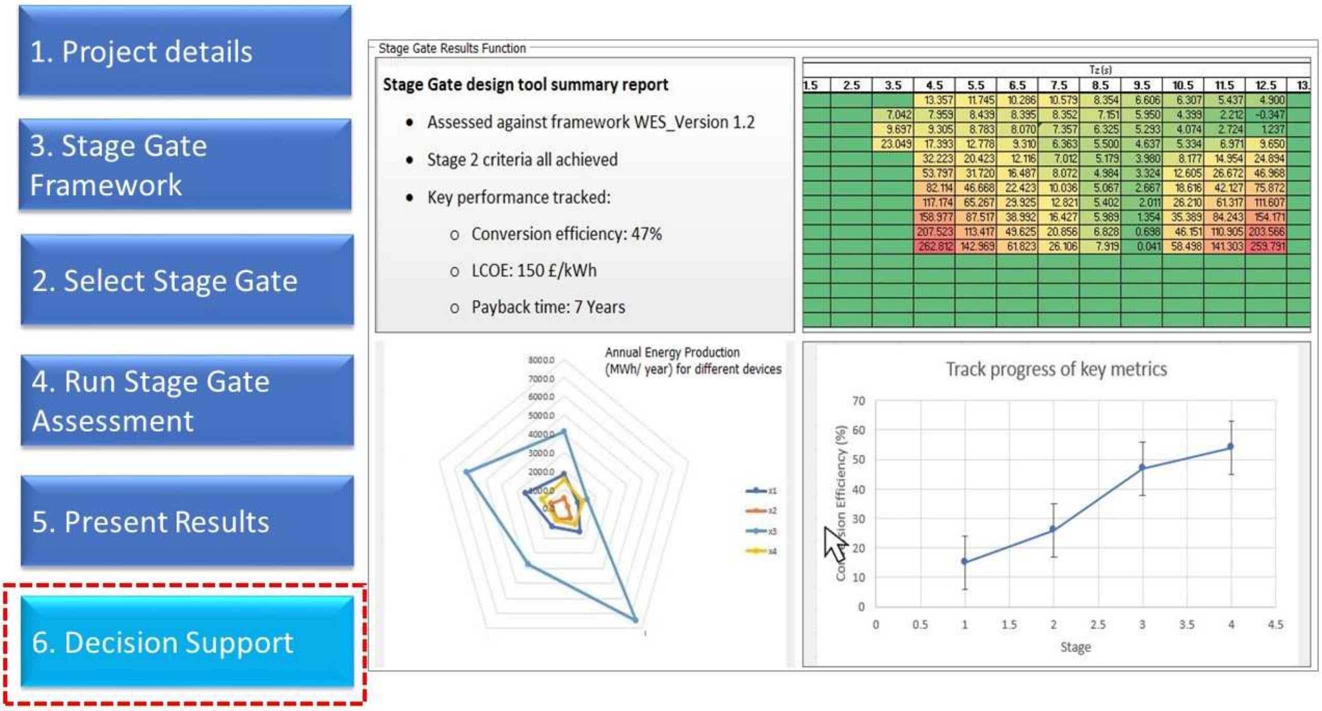

FIGURE 4.3 STAGE GATE DESIGN TOOL GRAPHICAL USER INTERFACE MOCK-UP: DISPLAYING RESULTS OF STAGE GATE ASSESSMENT

The figure above shows the options for presenting results. The user will be able to view and select from options and these will be based on the outputs of the assessment tools. Examples above show a summary report, a power matrix, overall view of all metrics and tracking of one key metric.

The GUI will display the key results of the Stage Gate design tool: A report summarising the set-up of the framework, the evaluation areas and key metrics selected, the thresholds set, the assumptions and context reference data used and any gap analysis.

It's expected that the report which is output from the Stage Gate design tool will be in a standardised format, and can be saved in the Digital Representation. Users will be able to run a stage gate assessment multiple times and have easily comparable reports from each run.

5. CONCLUSIONS AND NEXT STEPS

The addition of the Stage Gate design tool in the DTOceanPlus suite will facilitate the objective assessment of ocean energy technologies and support decision making in the technology development process.

This report outlined the uses and benefits of the stage gate process which is currently being used in industry.

The technical requirements specific to the development of each module within the Stage Gate design tool are defined in this report including the data required, methodologies, interactions with other tools within the DTOceanPlus suite, and outputs expected to meet the functional requirements [2].

The next task (Deliverable D4.2) is to develop the alpha version of the Stage Gate design tool based on these technical requirements. The alpha version will contain all the core functions of the tool in its simplified form with dummy links to the inputs and outputs. This version of the tool will contain the framework of the tool and its functional requirements, but not necessarily with the GUI. The coding of the tool will be done in Python using the PEP8 codes and the developed tool tested to ensure it meets all the requirements.

The beta-version will be a complete version of the tool with all the data flow, digital representation, public functions and interaction functions, including the GUI. The beta-version of the tool will be developed to fulfil the Deliverable D4.3 and will carry out validation of the tool in order to verify that it meets the requirements defined both in this report and in Deliverable D2.2 [18].

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