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

Deliverable D4.2

Stage Gate tool – Alpha version

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EXECUTIVE SUMMARY

Deliverable D4.2 "Stage Gate Tools – alpha version" of the DTOceanPlus project includes the details of the Stage Gate Design Tool, and it represents the result of the work developed during task T4.2 of the project. This tool is an application of a stage gate process which is used in research and industry to provide structure to the technology development process. This approach supports the R&D pathway towards producing reliable and cost-effective ocean energy sub-systems, devices and arrays.

The present document summarises both the functionalities, supporting theory, as well as the more technical aspects of the code implemented for this module. The Stage Gate module will provide the user with a framework to assess ocean energy technology, including guidance on the most appropriate Stage Gate Assessment, evaluation areas and metrics for measuring success. One of the main outputs of the tool will be a standardised report summarising the Stage Gate Assessment in order to inform the user of the stage of technology development and highlight any areas of improvement.

The Stage Gate design tool framework as outlined in this report includes description of stages and stage gates, evaluation areas, stage activities, data input, metrics and qualitative questions.

The Business Logic of the code, that implements the core functionality of the SG module, has been implemented in Python 3. An OpenAPI file has been created that describes the interface between the Business Logic and the Graphical User Interface (GUI), as well as the interface between the Stage Gate tool and the other DTOceanPlus tools. The Back-End implementation of this Application programming Interface (API) was also developed using Python 3 and the Flask Python package. A Graphical User Interface (GUI) was developed for the module using Vue.js and the Element component library. Sphinx was used to generate the technical documentation for the Python code. A unit-test coverage of 100% has been achieved for both the Business Logic and the Back-End layers of the tool, verifying the implemented methods and guaranteeing easy maintainability for future developments of the tool.

Several examples of the functionality of the developed software are given in Section 5 of the report, showcasing the current state of the tool and its capabilities. A section on the future work required to integrate the Stage Gate tool with the rest of the DTOceanPlus suite completes the present document.

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ABBREVIATIONS AND ACRONYMS

ACE	Average Climate Capture Width per Characteristic Capital Expenditure
API	Application Programming Interface
BOM	Bill of Materials
CAPEX	CAPital EXpenditure
C_P	Power coefficient
CRUD	Create, Read, Update and Delete
C_T	Thrust coefficient
CWR	Capture Width Ratio
DRP	Device Rated Power
EC	Energy Capture
ED	Energy Delivery
EIA	Environmental Impact Assessment
ESA	Environmental and Social Acceptance
ET	Energy Transformation
FEED	Front-End Engineering Design
FMEA	Failure Mode and Effects Analysis
GWP	Global Warming Participation
GUI	Graphical User Interface
HTTP	HyperText Transfer Protocol
LCOE	Levelised Cost of Energy
LMO	Logistics and Marine Operations
O&M	Operation and Maintenance
RAMS	Reliability, Availability, Maintainability, Survivability
REST	REpresentational State Transfer
rest	reStructured Text
SC	Site Characterisation
SG	Stage Gate
SI	Structured Innovation
SK	Station Keeping
SG	Stage Gate
SPEY	System Performance and Energy Yield
TEC	Tidal Energy Converter
TRL	Technology Readiness Level
UML	Unified Modelling Language
WEC	Wave Energy Converter

1. INTRODUCTION

1.1 SCOPE AND OUTLINE OF THE REPORT

This report is deliverable D4.2 "Stage Gate Tool – Alpha version" of the DTOceanPlus project, which provides details of the Stage Gate Design Tool and presents the result of the work developed during tasks T4.1 and T4.2 of the project. This document describes the technical details of the tasks that have been completed, including sections on the main functionalities of the tool, the implementation of the software architecture and several examples of module inputs and outputs. The alpha version of this tool is a fully functional version of the tool with a working Graphical User Interface (GUI) connected through a bespoke Application Programming Interface (API) to the Business Logic that implements the core functionality.

The remainder of this report is structured as follows:

- The supporting theory, definitions and underlying assumptions behind the Stage Gate module are given in Section 2.
- The use cases and the functionalities of the Stage Gate module are presented in Section 3.
- Section 4 details the actual implementation, describing the architecture of the tool, the technologies adopted for the implementation and the results of unit testing.
- Finally, Section 5 provides a set of extensive examples, to provide the reader with an overall view of the current status and capabilities of the module.

1.2 SUMMARY OF THE DTOCEANPLUS PROJECT

The Stage Gate module belongs to the design suite of tools "DTOceanPlus" developed within the EU-funded project DTOceanPlus (https://www.dtoceanplus.eu/). DTOceanPlus aims to accelerate the commercialisation of the Ocean Energy sector by developing and demonstrating an open source suite of design tools for the selection, development, deployment and assessment of ocean energy systems (including sub-systems, energy capture devices and arrays).

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

- **Structured Innovation Tool (SI),** for concept creation, selection, and design.
- **Stage Gate Tool (SG),** using metrics to measure, assess and guide technology development.
- **Deployment Tools,** supporting optimal device and array deployment:
  - *Site Characterisation (SC):* to characterise the site, including metocean, geotechnical, and environmental conditions.
  - *Machine Characterisation (MC):* to characterise the prime mover;
  - *Energy Capture (EC):* to characterise the device at an array level;
  - *Energy Transformation (ET):* to design PTO and control solutions;
  - *Energy Delivery (ED):* to design electrical and grid connection solutions;
  - *Station Keeping (SK):* to design moorings and foundations solutions;
  - *Logistics and Marine Operations (LMO):* to design logistical solutions operation plans related to the installation, operation, maintenance, and decommissioning operations.

- **Assessment Tools,** to evaluate projects in terms of key parameters:
  - *System Performance and Energy Yield (SPEY):* to evaluate projects in terms of energy performance;
  - *System Lifetime Costs (SLC):* to evaluate projects from the economic perspective;
  - *System Reliability, Availability, Maintainability, Survivability (RAMS):* to evaluate the reliability aspects of a marine renewable energy project;
  - *Environmental and Social Acceptance (ESA):* to evaluate the environmental and social impacts of a given wave and tidal energy projects.

These will be supported by underlying common digital models and a global database, as shown graphically in Figure 1-1.

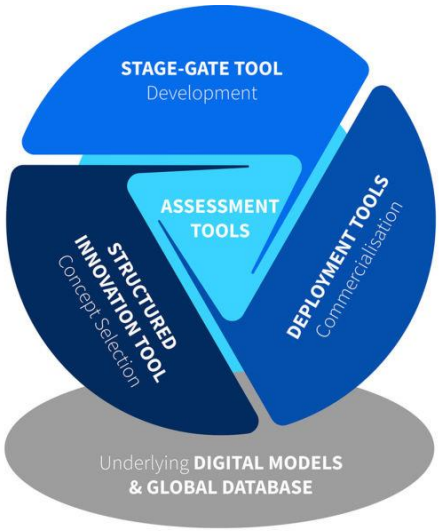


FIGURE 1-1: REPRESENTATION OF DTOCEANPLUS TOOLS

2. THEORY, DEFINITIONS AND ASSUMPTIONS

The Stage Gate design tool is a framework that guides a user through a technology assessment process. It is intended to be used by a wide variety of stakeholders, including:

- Technology developers in the evaluation of their own technology
- Investors and public funders to aid decision making on several technologies

The main features of the Stage Gate framework are:

- **Stages and stage gates**; The key feature of the stage gate design tool is the technology development pathway split up into distinct stages, separated by stage gates. The stage gates are an opportunity for users of the tool to assess the technology and make critical decisions on whether to progress to the next stage.
- **Evaluation Areas**; The areas in which the user wishes to measure the success of ocean energy technology to demonstrate progress and performance.
- **Stage activities**; This is a list of the research, development and demonstration activities that should be carried out during the prescribed stages.
- **Data Input**; The types of data which must be input to support a Stage Gate Assessment, including stage gate question responses, performance data e.g. tank and sea testing results and project data, e.g. site resource data which the user inputs to support the metrics calculations.
- **Metrics**; The parameters used to evaluate how well a technology performs in the Evaluation Areas. These are outputs of the Deployment and Assessment tools and are summarised in the Metrics section below.
- **Questions**; Qualitative and quantitative questions to support the Stage Gate Assessment, covering topics such as scientific and engineering credibility, future targets and readiness for the next stage.

Further detail on each of these features of the Stage Gate metrics framework can be seen in the sections below.

2.1 STAGES AND STAGE GATES

The Stage Gate process splits the technology development pathway into clearly defined stages, from a new concept, engineering specification, scaled prototypes, full devices and first arrays up until a commercially deployed array. Splitting the development pathway into clearly defined stages enables technologies to be compared within each stage and allows developers to understand where their technologies lie in the development process.

The Stage Gate design tool has six stages; Stage 0, 1, 2, 3, 4 and 5. These are separated by five stage gates: 0-1, 1-2, 2-3, 3-4 and 4-5, shown as diamonds in Figure 2-1.

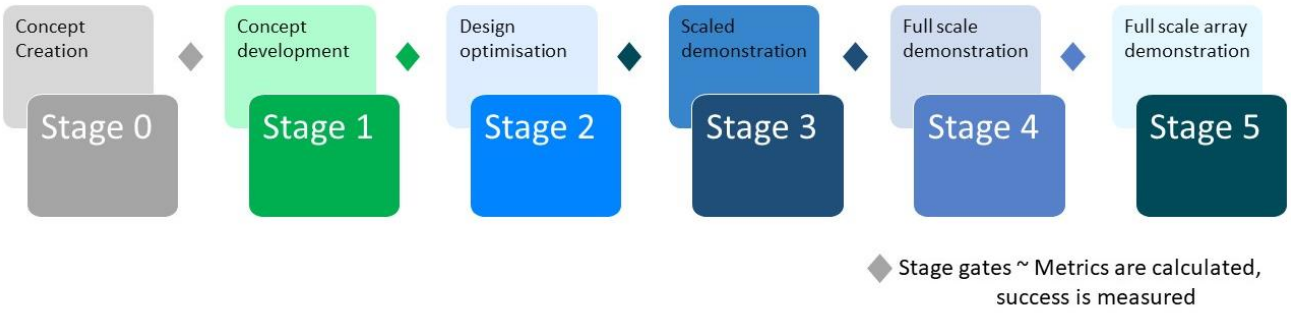


FIGURE 2-1: STAGES IN THE STAGE GATE DESIGN TOOL FRAMEWORK

Clear, defined stages in the technology development process are punctuated by the measures of success which are defined between stages at the stage gates. This is where objective measures of success can be defined and applied, namely metrics. An example of this process in industry is through the Wave Energy Scotland programme [1] which operates in a stage gate process for early stage concepts up until large scale prototypes. When Wave Energy Scotland funds R&D projects, the stage gates are the opportunities to measure success in order to decide which projects will pass through to the next stage to be awarded the next wave of funding.

The stage gate process helps to demonstrate to technology developers themselves, the public funders like Wave Energy Scotland and private investors in the sector that technologies are moving through these stages and maturing.

The maturity of technology is often measured by Technology Readiness Levels (TRLs) [2]. The stage gate design tool stages align with Technology Readiness levels as seen in Figure 2-2 below.

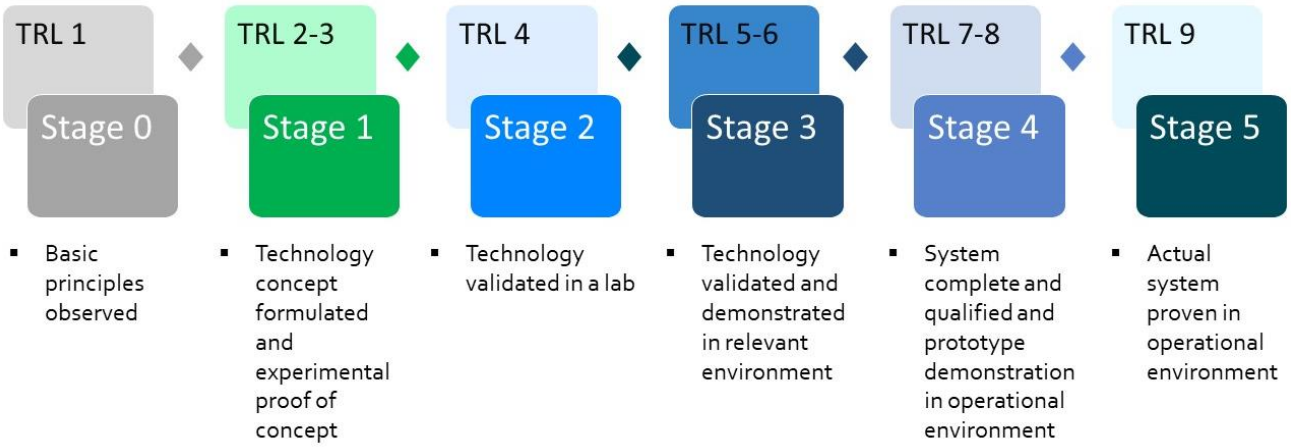


FIGURE 2-2: STAGES ALIGNED WITH TECHNOLOGY READINESS LEVELS

The alignment of stages and TRL levels is in accordance with the International Electrotechnical Commission (IEC) Technical Specification *IEC TS 62600-103* [3]. However, the IEC Stage 1 has been split into Stages 0 (TRL 1) and Stage 2 (TRL 2-3) in DTOceanPlus to ensure the DTOceanPlus suite of

tools is specifically able to function for the very earliest technologies (TRL 1) before any prototype testing has taken place in the technology development pathway.

The stage gate design tool will guide the user in identifying which stage gate their technology or project should be assessed against. This is done by displaying a list of technology development activities for the user to assess their progress and identify missed activities, as described in section 3.2.2.

2.2 EVALUATION AREAS

Table 2-1 lists the ten key Evaluation Areas in the Stage Gate design tool framework which will be used to assess ocean energy sub-systems, devices and arrays. This list has been developed through an iterative process, with consultation of the international ocean energy community [4]. Additionally, efforts have been made to align the Evaluation Areas and the four assessment categories that have been defined in DTOceanPlus; System Performance and Energy Yield (SPEY); Reliability, Availability, Maintainability and Survivability (RAMS); System Lifetime Costs (SLC) and Environmental and Social Acceptance (ESA). All the Evaluation Areas listed below, except for manufacturability, can be evaluated using the Deployment and Assessment tools.

The task of defining evaluation areas and metrics for consensus in the ocean energy sector is the focus of an activity called Task 12 [5] instigated by the International Energy Agency Ocean Energy Systems (IEA-OES) Technology Collaboration Programme. The IEA-OES has 25 contracting parties representing countries around the world and therefore provides an excellent platform for building consensus on this topic. DTOceanPlus partners are also integral to the delivery of Task 12 and therefore provide a link between the two activities, ensuring DTOceanPlus both leads and aligns with the agreed technology evaluation framework.

TABLE 2-1: TEN EVALUATION AREAS OF THE STAGE GATE METRICS FRAMEWORK

Evaluation Area	Definition
Affordability	The cost effectiveness of a technology ultimately indicated by Levelised Cost of Energy (LCOE).
Reliability	The ability of a structure or structural member to fulfil the specified requirements, during the working life, for which it has been designed [6].
Availability	The percentage of time that an ocean energy array/ farm is operational and generating electricity.
Maintainability	The ability of a system to be repaired and restored to service when maintenance is conducted by personnel using specified skill levels and prescribed procedures and resources [7].
Manufacturability	The ease with which an ocean energy technology can be manufactured.

Survivability	The probability that the converter will stay on station over the stated operational life [8]
Power Capture	Primary power conversion: from hydrodynamic power to any form of useful power (mechanical, hydraulic, pneumatic, …) which is input to the Power Take-Off (PTO).
Power Conversion	Secondary power conversion: from useful power i.e. input of PTO to electric power (output of PTO).
Installability	The ease with which an ocean energy technology can be installed.
Acceptability	The environmental and social acceptance of ocean energy technology.

Each of the Evaluation Areas listed above has associated Stage Activities, expectations of performance and project data inputs to make the assessment, and metrics which are either calculated or input by the user (as shown in Figure 2-3).

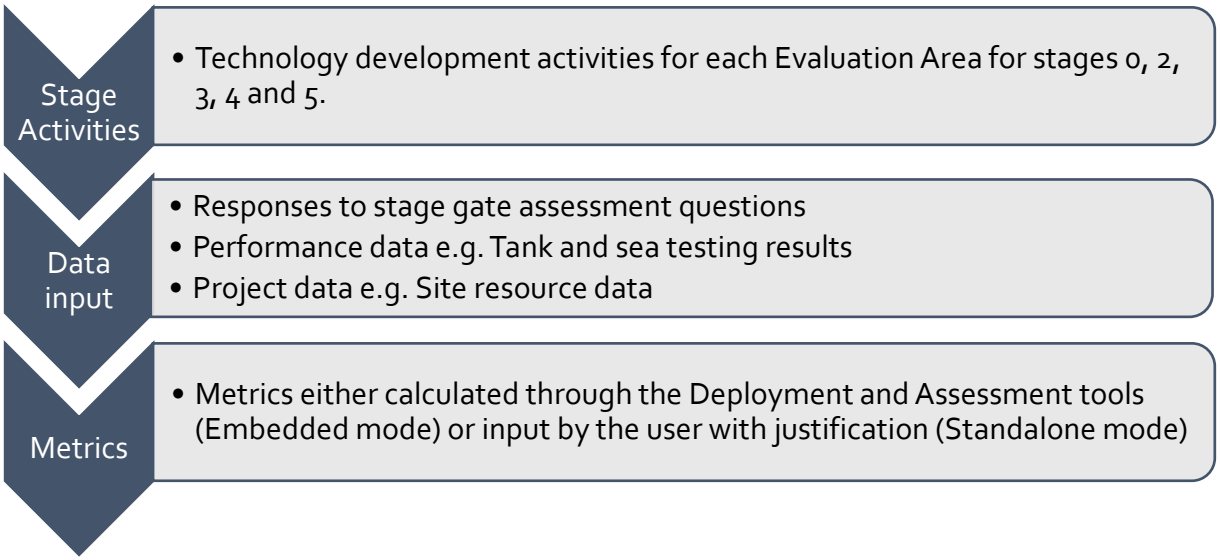


FIGURE 2-3: THE JOURNEY OF THE USER THROUGH THE SG TOOL: STAGE ACTIVITIES TO DATA INPUT TO METRICS IN THE SG ASSESSMENT

In the following sections (Stage Activities, Data input, Metrics), a summary is given of what this includes for each Evaluation Area.

2.3 STAGE ACTIVITIES

Before completing a Stage Gate Assessment in the SG design tool, the user must select which stage gate they would like to be assessed against. The Technology Readiness Level scale helps to guide the user on this.

Stage Activities are technology development actions which take place during the development of a technology, for example numerical modelling, tank testing, financial analysis. The Stage Gate design

tool will display a list of these activities, categorised per Evaluation Area, and split up into 6 stages (0, 1, 2, 3, 4, and 5) for the user to identify which activities have been completed. This will then guide the user to:

- identify the stage they are eligible to be assessed against and
- include the appropriate activities in their technology development programme.

A summary of the Stage Activities for each stage is presented below, per Evaluation Area.

2.3.1 AFFORDABILITY

Affordability is the cost effectiveness of a technology, which can be measured by the metric LCOE from stage 2 onwards, with increasing accuracy as more details are known about a project at higher TRL levels. The Stage Activities for Affordability which are outlined in Table 2-2 below reflect how the assessments which are possible at the earliest stages (Stages 0 and 1) are proxies or simplified calculations, which are can become higher detailed LCOE assessments from stage 2 onwards. Before LCOE can be calculated, proxies can be used to indicate how cost effective the technology may be, such as the ACE metric. More information on these assessment methods can be found in the *System Lifetime Costs – Alpha version* deliverable [9].

TABLE 2-2: AFFORDABILITY STAGE ACTIVITIES

Stage 0	▫ Basic Capital Expenditure (CAPEX) estimate ▫ Additional CAPEX detail ▫ Target selection
Stage 1	▫ CAPEX evaluation of Bill of Materials (BOM) ▫ Expand cost evaluation ▫ Calculate Levelised Cost of Energy (LCOE)
Stage 2	▫ Develop LCOE model ▫ Evaluate LCOE
Stage 3	▫ Optimise LCOE model ▫ Evaluate LCOE
Stage 4	▫ Complete BOM ▫ Finalise detailed LCOE model ▫ Apply final LCOE model
Stage 5	▫ Finalise array BOM ▫ Finalise LCOE model ▫ Apply final LCOE model

2.3.2 RELIABILITY

The Stage Activities for Reliability are those which will enable the calculation of 'probability of failure' and assess the ability of a structure or structural member to fulfil the specified requirements, during its design life. As can be seen in Table 2-3: below, the activities go from outlining target failure rates at Stage 0, through the development of a Failure Modes Effects Analysis (FMEA) at Stage 2, to

defining the open water testing requirements for reliability at Stage 5. These activities support the user being able to assess the metric of probability of failure (%) as outlined in Section 0.

TABLE 2-3: RELIABILITY STAGE ACTIVITIES

Stage 0	▫ Evaluation of comparable technologies ▫ Novelty evaluation ▫ Target selection (reliability) ▫ Potential for control systems
Stage 1	▫ Numerical model ▫ Structural component strength assessment ▫ Structural component safety factors ▫ Design limit states ▫ Identify failure modes
Stage 2	▫ Rig testing (reliability) ▫ Numerical model for full-scale loads ▫ Assess likely full-scale load factors ▫ Develop Failure Mode and Effects Analysis (FMEA)
Stage 3	▫ Open-water testing of device ▫ Open-water testing requirements ▫ Accelerated life testing of subsystem ▫ Numerical model (commercial-scale load) ▫ Load reduction analysis ▫ Record system failures and structural loads ▫ Develop commercial- scale FMEA
Stage 4	▫ Open-water testing of device ▫ Open-water testing requirements for reliability ▫ Accelerated life testing of subsystem ▫ Continuous monitoring for reliability
Stage 5	▫ Open-water testing of array ▫ Open-water testing requirements for reliability ▫ Accelerated life testing of device/subsystem ▫ Continuous monitoring for reliability ▫ Finalise reliability management approach

2.3.3 AVAILABILITY

The Stage Activities for Availability are seen in Table 2-4: below are those which enable the assessment of the time-based availability (%) metric. Availability is the combination of other Evaluation Areas such as:

- Reliability – for probability of failure
- Survivability – for probability of irreparable failure
- Maintainability – for time of maintenance activities

Therefore, the specific stage activities to calculate Availability are a combination of the activities which will be completed for these Evaluation Areas, and include development of an FMEA, O&M model and open water testing to validate these models.

TABLE 2-4: AVAILABILITY STAGE ACTIVITIES

Stage 0	▫ Evaluation of comparable technologies ▫ Novelty evaluation ▫ Target selection for availability
Stage 1	▫ Integrate FMEA and Operations and Maintenance (O&M) plan
Stage 2	▫ Integrate FMEA and O&M model
Stage 3	▫ Open-water testing of device ▫ Validate availability ▫ Integrate FMEA and O&M model
Stage 4	▫ Open-water testing of device ▫ Validate availability ▫ Integrate FMEA and O&M model
Stage 5	▫ Validate availability ▫ Complete integration of FMEA and O&M model

2.3.4 MAINTAINABILITY

The Stage Activities for Maintainability are those which enable the calculation of metrics such as Probability that a maintenance action can be carried out (%) and Maintenance duration (hours/kW/year). At the earliest stages (Stages 0 and 1), before an O&M model is developed, it is not possible to calculate these metrics with any level of certainty. As can be seen in Table 2-5: below, the stage activities go from selecting maintainability targets, to developing an O&M model and eventually practically demonstrating an O&M plan in open water testing.

TABLE 2-5: MAINTAINABILITY STAGE ACTIVITIES

Stage 0	▫ Potential for control systems ▫ Evaluation of comparable technologies ▫ Novelty evaluation ▫ Target selection for maintainability
Stage 1	▫ Concept characterisation (maintainability) ▫ Develop high-level O&M process
Stage 2	▫ Characteristics optimisation ▫ Develop O&M model ▫ Highlight failure modes using O&M model
Stage 3	▫ Practical demonstration of O&M plan ▫ Develop complete O&M model and plan ▫ Use O&M model to highlight failure modes ▫ HSE action definition
Stage 4	▫ Open-water testing of device ▫ Practical demonstration of O&M plan ▫ Update O&M model ▫ Use O&M model to highlight failure modes ▫ HSE action definition

Stage 5	▫ HSE action definition Practical demonstration of O&M plan ▫ Update O&M model ▫ Use O&M model to highlight failure modes

2.3.5 MANUFACTURABILITY

The Stage Activities for Manufacturability are outlined in Table 2-6: below. The ease of manufacture is generally measured with metrics such as the time and cost to manufacture. Alongside this, the Manufacturing Readiness Level (MRL) can be used as a measure of the readiness of a manufacturing process. This is a quantitative measure of the maturity, risk, cost, scalability and feasibility of manufacturing processes [10]. As can be seen in Table 2-6:, the technology development activities which are to be completed at each stage to assess these metrics range from identifying the main materials at Stage 0, to creating a full Bill of Materials (BOM) and finalising the commercial-scale BOM at Stage 5.

TABLE 2-6: MANUFACTURABILITY STAGE ACTIVITIES

Stage 0	▫ Materials identification ▫ Sizing estimates for structure
Stage 1	▫ Demonstration of manufacturing process (tank tests) ▫ Demonstration of manufacturing process (rig tests) ▫ Simple subsystem breakdown ▫ Outline manufacturing process ▫ Manufacturing feasibility assessment
Stage 2	▫ Small-scale manufacturing process ▫ Front-End Engineering Design (FEED) for larger-scale technology ▫ Manufacture small-scale prototype ▫ Large-scale manufacturing process ▫ Manufacturing feasibility assessment ▫ Manufacturing cost and duration assessment
Stage 3	▫ Large-scale manufacturing process ▫ Manufacture large-scale prototype ▫ Manufacturing process demonstration ▫ FEED of commercial-scale technology ▫ Commercial-scale manufacturing process ▫ Manufacturing cost and duration assessment
Stage 4	▫ Commercial-scale manufacturing process ▫ Manufacture commercial-scale device ▫ Verify manufacturing costs and durations
Stage 5	▫ Optimise commercial-scale manufacturing process ▫ Manufacture sea-going devices ▫ Finalise commercial-scale BOM ▫ Verify manufacturing costs and durations

2.3.6 SURVIVABILITY

The Stage Activities for Survivability are similar to those for Reliability in that they range from target selection at Stage 0, to numerically modelling loads and finally open water demonstration of survival strategies. The activities are there to enable the calculation of the metric of probability of structural irreparable failure (%) and are outlined in Table 2-7:below.

TABLE 2-7: SURVIVABILITY STAGE ACTIVITIES

Stage 0	▫ Evaluation of comparable technologies ▫ Novelty evaluation ▫ Target selection for survivability
Stage 1	▫ Concept characterisation ▫ Numerical model (extreme loads) ▫ Structural component strength assessment ▫ Structural component safety factors ▫ Design limit states for survivability
Stage 2	▫ Rig testing (survivability) ▫ Perform tank testing for survivability ▫ Evaluate survival strategies ▫ Evaluate behaviour in extreme conditions ▫ Measure structural forces ▫ Numerical model for extreme loads ▫ Assess commercial scale safety factors
Stage 3	▫ Open-water testing of device ▫ Open-water testing requirements (survivability) ▫ Demonstration of survival strategies ▫ Rig testing for extreme structural loads ▫ Tank testing for extreme structural loads ▫ Numerical model (extreme loads) ▫ Develop commercial scale FMEA
Stage 4	▫ Open-water testing of device ▫ Open-water testing requirements (survivability) ▫ Rig testing for extreme structural loads ▫ Continuous monitoring (survivability) ▫ Develop commercial-scale FMEA ▫ Demonstration of survival strategies
Stage 5	▫ Demonstration of survival strategies Open-water testing requirements (survivability) ▫ Continuous monitoring for survivability

2.3.7 POWER CAPTURE

The Stage Activities for power capture are outlined in Table 2-8:below for each of the stages, with the aim of enabling the calculation of hydrodynamic efficiency (%) and hydrodynamic annual captured energy (kWh/year). Ranging from Stage 0 to Stage 5, the level of detail known about the technology

increases and this is reflected in the Stage Activities going from basic hydrodynamic calculations of, for example, capture width ratio, to the production of a full power matrix from open water testing.

TABLE 2-8: POWER CAPTURE STAGE ACTIVITIES

Stage 0	▫ Basic hydrodynamic calculations ▫ Hydrodynamic performance estimates ▫ Device concept definition
Stage 1	▫ Tank testing of energy capture technology ▫ Evaluation of tank testing ▫ Numerical model (hydrodynamic performance) ▫ Validate numerical model
Stage 2	▫ Perform tank testing for performance ▫ Integrate device and PTO ▫ Numerical model for hydrodynamic performance ▫ Validation of hydrodynamic numerical model
Stage 3	▫ Open-water testing of device ▫ Open-water testing requirements for energy capture ▫ Tank testing of energy capture technology ▫ Numerical model (integrated PTO)
Stage 4	▫ Open-water testing ▫ Open-water testing requirements for energy capture and control ▫ Integrated numerical model ▫ Validate integrated numerical model
Stage 5	▫ Select array layout ▫ Open-water testing of array ▫ Open-water testing requirements for energy capture ▫ Integrated numerical model for array ▫ Optimise controllable parameters

2.3.8 POWER CONVERSION

The Stage Activities for the Evaluation Area of Power Conversion can be seen in Table 2-9: below, and ultimately outline the technology development activities which must be undertaken at each stage to enable to calculation of metrics such as transformed and delivered efficiency (%), and annual transformed and delivered energy (kWh/year). The range of activities seen in Table 2-9: covers the concept definition of the PTO at Stage 0, through to the results of rig testing at Stage 3 and finally open water testing of the PTO and validation of a numerical model at Stage 5.

TABLE 2-9: POWER CONVERSION STAGE ACTIVITIES

Stage 0	▫ PTO concept definition ▫ Additional energy transformation details
Stage 1	▫ Rig testing of subsystems ▫ Numerical model for energy transformation
Stage 2	▫ Rig testing (PTO) ▫ Integrate device and PTO ▫ Numerical model for energy transformation ▫ Validation of energy transformation numerical model

Stage 3	▫ Rig testing of complete PTO system ▫ Numerical model (energy transformation) ▫ Validate numerical model with rig data
Stage 4	▫ Integrate commercial device and PTO ▫ Open-water testing requirements for energy transformation ▫ Rig testing of commercial-scale PTO ▫ Integrated numerical model ▫ Validate integrated numerical model
Stage 5	▫ Integrate device and PTO for multiple devices ▫ Open-water testing requirements for energy transformation ▫ Validate integrated numerical model

2.3.9 INSTALLABILITY

The Stage Activities for Installability are there to enable the calculation of metrics such as the installation duration (hours) and the cost of installation (€). The range of activities which enable these calculations start at Stage 0 as an outline of the impact of a concept on installation and move on to developing an increasingly detailed installation plan at stages 1 -4, with this plan being practically demonstrated in open water testing. A summary of these activities is outlined in Table 2-10: below.

TABLE 2-10: INSTALLABILITY STAGE ACTIVITIES

Stage 0	▫ Impact of control systems on installability ▫ Evaluation of comparable technologies ▫ Novelty evaluation ▫ Target selection
Stage 1	▫ High-level installation plan ▫ Concept characterisation (installability)
Stage 2	▫ Characteristics optimisation (installability) ▫ Develop installation plan
Stage 3	▫ Develop complete installation plan ▫ Independent review of installation plan ▫ Open-water testing of device ▫ Practical demonstration of installation plan
Stage 4	▫ Develop commercial-scale installation plan ▫ Independent review of installation plan ▫ Open-water testing of device ▫ Practical demonstration of installation plan
Stage 5	▫ Optimise commercial-scale installation plan ▫ Independent review of installation plan ▫ Practical demonstration of installation plan

2.3.10 ACCEPTABILITY

Environmental and social acceptability is an Evaluation Area which assesses metrics such as the number of jobs an ocean energy project creates, the Global Warming Participation (GWP) (gCO_2/kWh)

and cost of consenting (€/MW). In order to calculate these metrics, the stage activities as outlined in Table 2-11:below outline how the activities range from assessing potential deployment sites for projects to a full Life Cycle Analysis (LCA) in Stage 5.

TABLE 2-11: ACCEPTABILITY STAGE ACTIVITIES

Stage 0	▫ Acceptability assessment
Stage 1	▫ General acceptability evaluation
Stage 2	▫ Evaluate environmental impact of manufacturing ▫ Assess potential deployment sites
Stage 3	▫ Evaluate CO_2 emissions of vessels ▫ Evaluate CO_2 emissions of manufacture ▫ Estimate social value of project ▫ Identify stressors and receptors
Stage 4	▫ Create baseline Environmental Impact Assessment (EIA) ▫ Evaluate CO_2 emissions of vessels ▫ Evaluate CO_2 emissions of manufacture ▫ Calculate social value of project ▫ Identify stressors and receptors
Stage 5	▫ Use O&M Model to inform EIA ▫ Evaluate greenhouse gas emissions ▫ Refine baseline EIA ▫ Life cycle analysis (LCA) ▫ Calculate social value of project ▫ Identify stressors and receptors

2.3.11 STAGE ACTIVITY SUMMARY

As can be seen in Table 2-2 – Table 2-11: above, requirements for a technology to be eligible for a Stage Gate Assessment move from target selection, i.e. predictions of technology performance in the future, towards open water testing at the later stages. Users of DTOceanPlus will have more data and detail about their technology at later stages and therefore the activities which are expected to have been completed become more detailed. activities which are expected to have been completed become more detailed.

The user will be able to click on any of these activities and receive more detail about that activity, to ensure they have completed them sufficiently.

For example, the Stage 0 Activities for the Evaluation Area of Survivability for 'Concept Creation' are:

- Evaluation of the novelty of the technology with respect to the state of the art and experience of its application in the ocean energy environment
- Evaluation of the survivability of comparable technologies and applications. This evaluation should be based on the conceptual understanding of the technology and identification of physical and functional characteristics that impact survivability, including:
  - surface piercing/floating/bottom mounted
  - suitability for implementation of protective control and monitoring systems

- proposed structural material considered with respect to scale and extreme loading scenarios and suitability for expected environmental exposure
- concept mode of operation and any fundamental characteristics that improve the ability to survive extreme conditions

- Selection of high-level survivability targets appropriate to the technology

For a full list of Stage Activities for all stages and Evaluation Areas, go to the Annex section A.

This is a key part of the functionality of the stage gate design tool and has been designed to be coherent with IEC standards [3], aiming to provide some sector wide consistency in how stages in ocean energy technology are defined. This work is coherent with the ongoing IEA-OES Task 12 on achieving a consensus on how success is measured for ocean energy technology [5].

2.4 DATA INPUT

As can be seen in section 2.3, the later stage gates require more data inputs from the users than the earlier stage gates. This data comes in the forms of responses to Stage Gate Assessment questions, performance data and project data, as outlined below.

2.4.1 RESPONSES TO STAGE GATE ASSESSMENT QUESTIONS

As is described further in sections 2.5 and 2.6, the user can respond to a Stage Gate assessment with both qualitative and quantitative responses to questions.

2.4.2 PERFORMANCE DATA

As a technology matures and more data is available from tank testing and open water testing, the user is expected to input more detailed performance data through the Deployment and Assessment tools. This data is produced in the technology development process and increases in detail and confidence-level as a technology matures. As part of DTOceanPlus, the user can import this data to support their design and assessment. As an example, for the Evaluation Area of Power Capture, the increasing detail of performance data changes for different Stage Gate Assessments as follows[1]:

- **Stage gate 0-1**
  - Tidal: single value for power coefficient (C_P) of the machine that represents the efficiency of the machine
  - Wave: single value for Capture Width Ratio (CWR)
- **Stage gates 1-2, and 2-3**
  - Wave: the power matrix or CWR matrix for tank testing or numerical modelling of device
  - Tidal: curve of the power coefficient (C_P) and thrust coefficient (C_T) of the machine for flume testing or numerical modelling of device
- **Stage gate 3-4 and 4-5**

[1] This data is alongside other key parameters such as 'Rated power of a single device', 'main dimension of the device', 'secondary dimension of the device'.

- Wave: Numerical model power matrices, including device interaction, informed from open water testing power matrix
- Tidal: Numerical model power matrices, including device interaction, informed from open water testing C_P and C_T curves.

As is explained further in section 3.1.1 the user may be prompted to input their performance data through the Deployment and Assessment modules when completing a Stage Gate Assessment.

2.4.3 PROJECT DATA

As with Performance data, a user is likely to know more about their ocean energy project with increasing maturity. This means that when completing a Stage Gate Assessment, the higher stage gates will be able to define parameters such as the location of their chosen site, the distance between devices in an array, or have more confidence in the logistics and maintenance activities to support the project, as these will be informed from deployment in open sea.

When completing a Stage Gate Assessment, the user will see from the Stage Activities that this expectation of knowledge of project data gets increasingly demanding.

For example, when inputting site data through the Site Characterisation tool, the user may select a reference site for the earliest stage gate deciding on low, medium or high wave and tidal energy sites. For later stage gates, the user will be able to upload their own resource and bathymetry data as a site is known.

These input data are there to allow the calculation of metrics, which is described in more detail in section o below.

2.5 METRICS

Metrics are the quantitative measures which are used to assess technology. Table 2-12 below summarises the key metrics which are calculated through the Deployment and Assessment tools at the late Stage Gate assessments (not all are possible at the earlier stage gates due to lack of data and information).

TABLE 2-12: STAGE GATE METRICS USED IN STAGE GATE ASSESSMENT

Stage Gate Metric		
Evaluation Area	**Deployment or Assessment tool**	**Metric (units)**
Affordability	System Lifetime Costs (SLC)	LCOE (€/kWh)
		CapEx (€)
		CapEx per kW (€/kW)
		OpEx (€)
		OpEx per kW per year (€/kW/year)
		Internal Rate of Return (%)
Reliability	RAMS	Probability of failure of system (%)
Availability	RAMS	Time-based availability (%)

Maintainability	RAMS	Probability that a maintenance action can be carried out (%)
	Logistics and Marine Operations (LMO)	Average maintenance duration per kW (hours per kW per year)
Installability	Logistics and Marine Operations (LMO)	Average installation duration (hours per kW)
		Cost of Installation (€)
Survivability	RAMS	Probability of structural irreparable failure (%)
Power Capture	System Performance and Energy Yield (SPEY)	Array annual captured energy (kWh)
		Captured efficiency (%)
Power Conversion	System Performance and Energy Yield (SPEY)	Array annual transformed energy (kWh)
		Transformed efficiency (%)
		Array annual delivered energy (kWh)
		Delivered efficiency (%)
Acceptability	Environmental and Social Acceptance (ESA)	Global negative Environmental Impact Assessment score
		Global positive Environmental Impact Assessment score
		Number of jobs created
		Cost of consenting (€)
		Global Warming Participation (gCO_2/kWh)
		Cumulative energy demand (kJ/kWh)

2.6 QUALITATIVE STAGE GATE QUESTIONS

When completing a Stage Gate Assessment, qualitative questions will be displayed to the user to answer with a narrative to support their stage gate application. These questions cover areas including scientific credibility, innovation, technology risks and future commercial offering.

This part of the Stage Gate Assessment gives value to investors and funders who are marking a Stage Gate assessment, as it gives the extra information on an ocean energy project needed to justify the provided data and other project results. In particular, the qualitative questions give the opportunity to provide more detail at the earliest stage assessments. When more detail is defined about a project and there are more measurable parameters at the later stages, there is a decreasing need for the additional qualitative narrative to support it. For this reason, there are qualitative questions for stages gates 0-1, 1-2 and 2-3 only. Figure 2-4 below shoes the transition from high-level quantitative combined with qualitative evaluation towards full quantitative detail in the Stage Gate design tool.

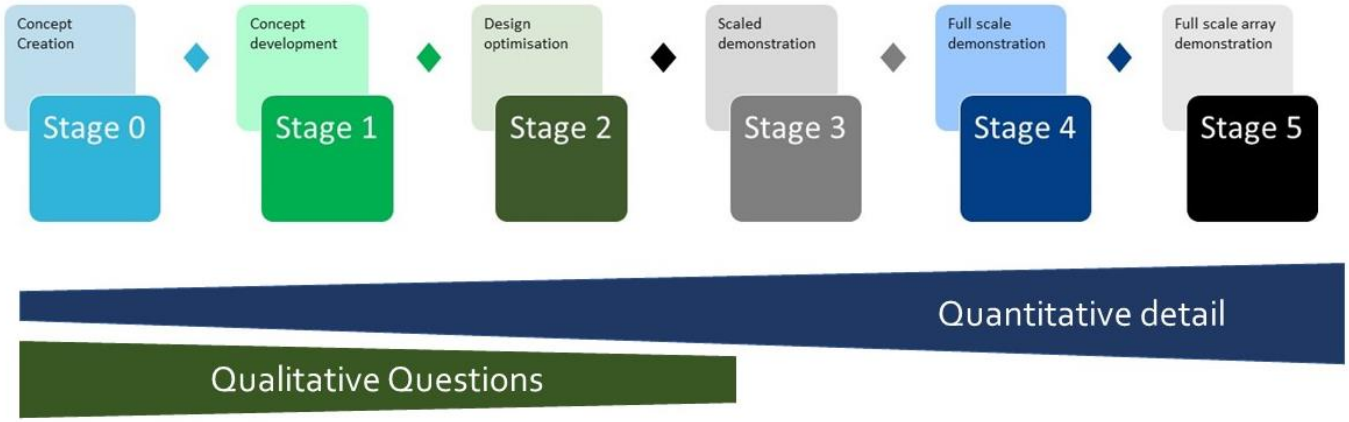


FIGURE 2-4: QUALITATIVE AND QUANTITATIVE QUESTIONS FOR STAGES 0-5

The qualitative questions help assess a range of factors which affect the technical credibility of an ocean energy project. The questions were created from input from the Wave Energy Scotland programme [1], with adaptation for DTOceanPlus. Therefore, the questions are based on tried and tested Stage Gate Assessments in ocean energy. A summary of the questions for Stage Gates 0-1, 1-2 and 2-3 are seen in Table 2-13: below.

TABLE 2-13: SUMMARY OF SUBJECTS OF QUESTIONS FOR STAGE GATES 0-1, 1-2 AND 2-3

Stage Gate	Subject of question
0-1	▫ Scientific credibility ▫ Technical credibility ▫ Engineering credibility ▫ Innovation ▫ Disadvantages ▫ Integration and systemisation ▫ Diversity ▫ Absolute long-term levelised cost of energy potential ▫ Relative LCOE potential ▫ Absolute long-term potential ▫ Utility-scale relevance
1-2	▫ Engineering description of technology ▫ Degree of novelty and innovation ▫ Technology readiness ▫ Technical risks ▫ Business case and impact
2-3	▫ Scaled, sea-going prototype characteristics ▫ Readiness to enter Stage 3 ▫ Device characteristics and Stage 2 performance ▫ Technology risks ▫ Technology selling points ▫ Commercialisation route

As can be seen in Table 2-13: above, the questions associated with each of the subjects listed above are appropriate for the level of maturity of the technology. The questions are accompanied by Scoring Criteria which can be used to assess the Stage Gate application, providing guidance to the assessor and thereby reducing subjectivity. In the following sections, examples of both questions and scoring criteria for Stage Gates 0-1, 1-2 and 2-3 are outlined. Full details of questions and associated Scoring Criteria are provided in section 0.

2.6.1 STAGE GATE 0-1

Stage 0 is 'Concept creation' and the questions in the application form are appropriate for TRL 1 i.e. basic principles have been observed. The breadth of the questions covered in the first Stage Gate 0-1 covers a range of criteria, for example:

- Scientific credibility
  - As evidence applicants should demonstrate how the underlying physical and scientific principles of energy conversion have been identified, understood and described in a concise technology description,
  - the basic hydrodynamic philosophies, likely properties, operational characteristics and interaction of the concept with the wave/tidal resource have been thought through and can be explained,
  - subtleties and elegancies in the concept can be explained scientifically.
- Technical credibility
  - Applicants may wish to provide the following as evidence a qualitative description (maybe supplemented by basic analysis and/or simulations), detailing how the concept can be designed or controlled so as to perform efficiently in the design wave/tidal conditions, but can regulate power and can shed load in more extreme conditions,
  - an identification of the factors which are likely to influence performance, response and loading (typically related to dimensions, dimensional rations and dynamic characteristics) and how they will be explored,
  - evidence of understanding of how the primary concept might interface with other elements of the system,
  - an outline of the approach to the early development of the concept, showing for instance exploration of many options using critical techniques such as design inversion and lateral thought,
  - a list of lab or tank test work carried out and/or simulation and modelling work which has been done to prove the viability of the concept.

To support this, the scoring criteria are defined for the assessing of the application forms. For Stage Gate 0-1 the scoring criteria for the first two criteria are outlined below.

TABLE 2-14: EXAMPLE OF SCORING CRITERIA FOR STAGE GATE 0-1

Name	Scoring criterion 1	Scoring Criterion 2
Scientific credibility	Concept operation and performance is demonstrated to be in alignment with scientific and hydrodynamic principles.	The principles of operation are insightful and are driven by a good understanding of the underlying physics.
Technical credibility	The concept addresses the need for efficient performance in the design wave/tidal conditions.	The concept addresses the need to regulate power and shed load in more extreme conditions.

2.6.2 STAGE GATE 1-2

Stage 1 is 'Concept Development' and the questions in the application form are appropriate for TRL 2-3 where technology concept has been formulated and experimental proof of concept has been completed. The breadth of the questions covered in the first Stage Gate 0-1 covers a range of criteria, for example:

- Technology readiness
  - Describe the current state of technology development and the anticipated trajectory of development required to permit large scale testing in the marine environment in the near to medium term (3-5 years). Provide evidence to support this.
- Degree of novelty and innovation (II)
  - Describe why the innovations could be considered a significant step change alternative to existing state of the art ocean energy technologies.

To support this, the scoring criteria are defined for the assessing of the application forms. For Stage Gate 0-1 the scoring criteria for the first two criteria are outlined below.

To support this, the scoring criteria are defined for the assessing of the application forms. For Stage Gate 0-1 the scoring criteria for the first two criteria are outlined below.

TABLE 2-15: EXAMPLE OF SCORING CRITERIA FOR STAGE GATE 1-2

Name	Scoring criterion 1	Scoring Criterion 2
Technology readiness	The trajectory of technology development is credible.	The underpinning technologies to facilitate large scale testing this WEC/TEC design are identified.
Degree of novelty and innovation (II)	Justification for a significant step change alternative to existing state of the art ocean energy technologies.	Identification of the attractions and advances in availability, performance, affordability and survivability offered by this solution over current state-of-the-art alternatives.

2.6.3 STAGE GATE 2-3

Stage 2 is 'Design optimisation' and the questions in the application form are appropriate for TRL 4 where technology has been validated in lab conditions. The breadth of the questions covered in the first Stage Gate 0-1 covers a range of criteria, for example:

- Scaled, sea-going prototype characteristics
  - The purpose of this question is to provide Assessors of this Application Form with information about the baseline for the current state of the technology, the fundamental technical and engineering principles, the requirements for integration of subsystems, and the proposed design geometry.
- Commercialisation route
  - How the technology will become commercially competitive for utility scale energy generation in the long term.
  - What is the current trajectory for the technology, recognising both its inherent strengths and weaknesses?
  - Which intermediate development steps are necessary in order to become commercially competitive?

To support this, the scoring criteria are defined for the assessing of the application forms. For Stage Gate 0-1 the scoring criteria for the first two criteria are outlined below.

TABLE 2-16: EXAMPLE OF SCORING CRITERIA FOR STAGE GATE 2-3

Name	Scoring criterion 1	Scoring Criterion 2
Technology risks	A comprehensive set of risks are presented identifying the main areas of concern with the proposed technology.	Appropriate and achievable mitigations are presented to reduce the identified risk scores.
Commercialisation route	Strength of commercial argument proposed by Applicant.	Credible, intermediate technology development steps are indicated and justified in the context of the plan for the long-term development of the technology and the challenges and limits which exist.

3. USE CASES AND FUNCTIONALITIES

The Stage Gate (SG) module guides the technology development process and facilitates the assessment of ocean energy technologies. It does this by implementing a bespoke Stage Gate framework and assessment process based on the theory, definitions and assumptions outlined in section 2. This section describes the use cases and functionalities of the SG module as well as the methods that enable integration with the other DTOceanPlus modules.

3.1 THE USE CASES

Four key user groups were identified as part of the development of the functional requirements for the Stage Gate module (see [11] for more details):

- Funders and Investors
- Innovators and Developers
- Project Developers
- Policy-makers and Regulators

A generic use case diagram for the SG module is given in Figure 3-1. This shows the various use cases of the module and how they apply to each of the user groups listed above. A significant difference between the use cases is that Innovators and Developers are more likely to use the Applicant Mode functionality, while Funders, Investors, Policy-makers and Regulators are expected to be more interested in the Assessor Mode functionality. These two functionalities are discussed in more detail in sections 3.2.3 and 3.2.4 respectively.

In the following sub-sections, the use cases are described from an operational perspective, with respect to what the user decides to do and which modules the user runs. The SG use cases can be categorised according to the integration with the other DTOceanPlus modules. As such, the user can:

1) Run SG in embedded mode by
    a. integrating with the Deployment and Assessment modules and/or
    b. integrating with the Structured Innovation module.
2) Run SG in standalone mode.

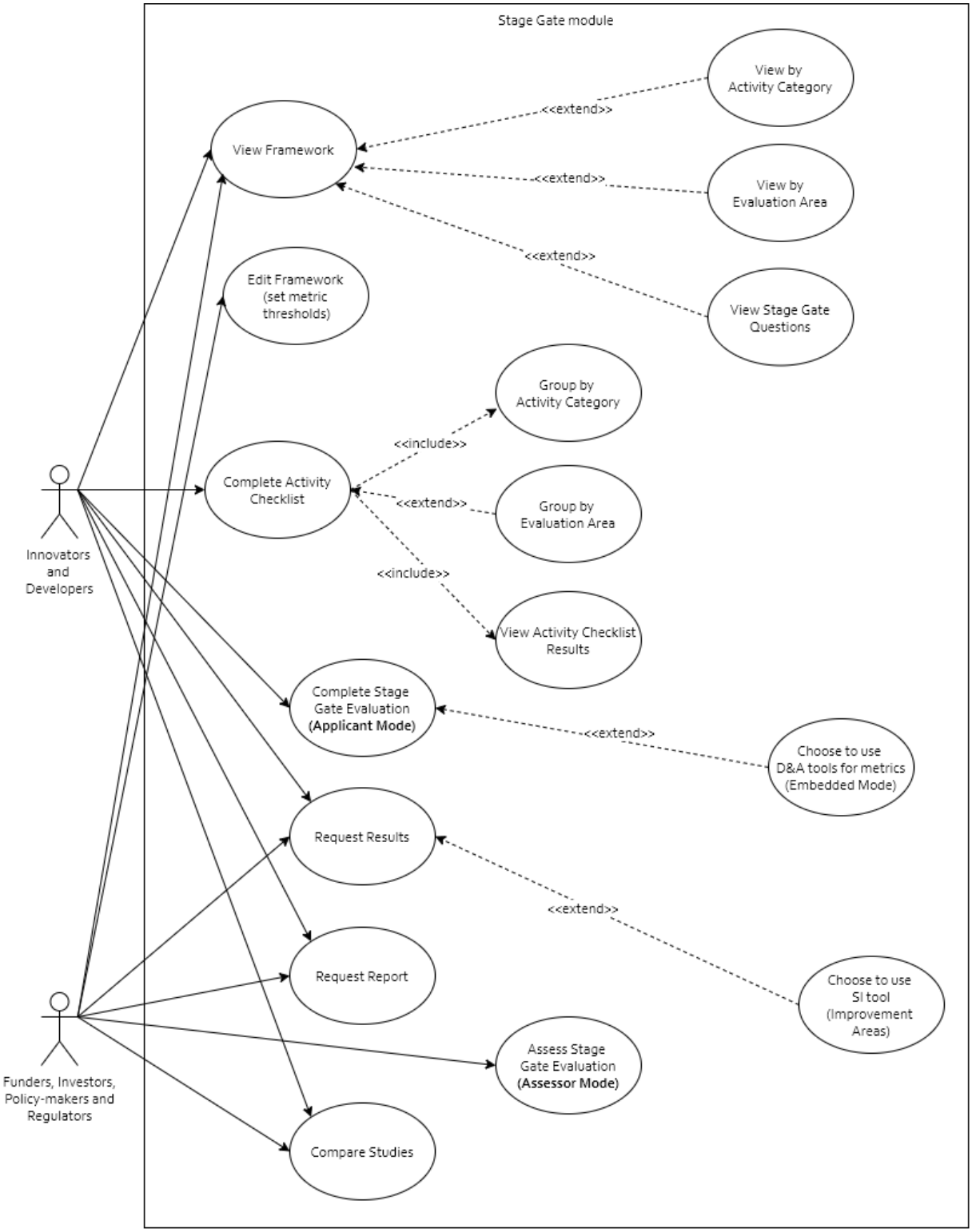


FIGURE 3-1: GENERIC USE CASE DIAGRAM FOR THE STAGE GATE MODULE

3.1.1 INTEGRATION WITH DEPLOYMENT AND ASSESSMENT MODULES

The Stage Gate module is integrated with the Deployment and Assessment tools in two main ways. These are summarised in Figure 3-2.

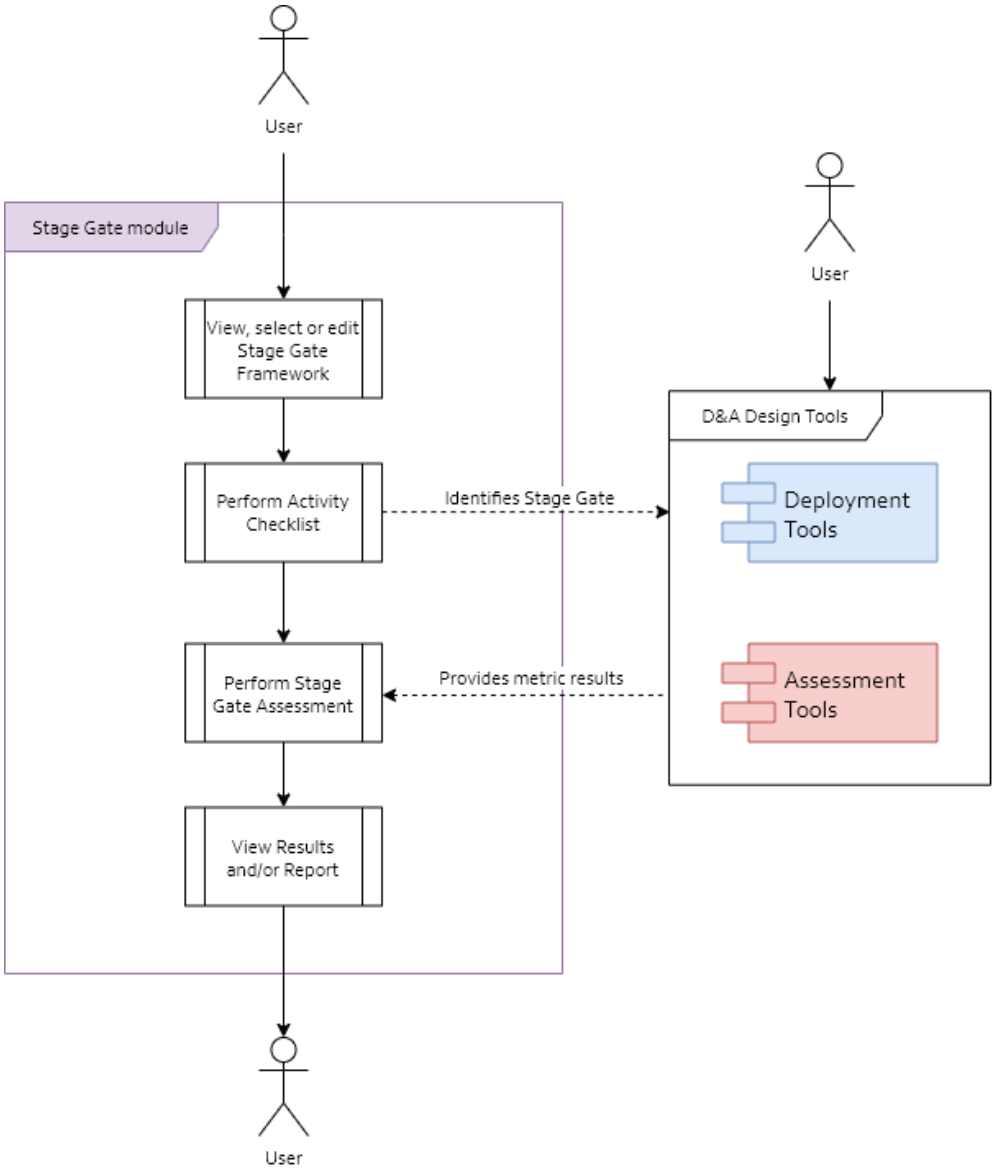


FIGURE 3-2: INTEGRATION OF STAGE GATE WITH THE DEPLOYMENT AND ASSESSMENT TOOLS

Firstly, the **Activity Checklist** functionality can be used to identify the *stage* of development of a device or technology (see section 3.2.2 for more details), which in turn identifies the appropriate *stage gate* that the technology should be evaluated against. A user can run each of the Deployment and Assessment tools at varying levels of complexity. A pre-defined mapping between the *stages* and *complexity levels* of the Deployment and Assessment tools has been defined. This is referred to as the *Combination Matrix* and is shown in Table 3-1. This matrix allows the Activity Checklist functionality to inform the user of the appropriate complexity level to use for each of the Deployment and

Assessment tools. Furthermore, the stage activities have been developed in tandem with the user inputs of the Deployment and Assessment tools for each level of complexity. As such, a user can ensure they have the user inputs required to run each tool at the appropriate level of complexity if they first use the Activity Checklist functionality in the Stage Gate module. Note that the System Performance and Energy Yield (SPEY) tool works in the same way at each complexity level.

TABLE 3-1: COMBINATION MATRIX LINKING STAGES AND COMPLEXITY LEVELS OF OTHER TOOLS

Tool	Stage 0	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Site Characterisation (SC)	1	1	2	2	3	3
Energy Capture (EC)	1	2	2	3	3	3
Energy Transformation (ET)	1	2	2	3	3	3
Energy Delivery (ED)	1	1	1	2	3	3
Logistics and Marine Operations (LMO)	1	1	2	2	2	3
Station Keeping (SK)	1	1	1	2	3	3
Reliability, Availability, Maintainability, Survivability (RAMS)	1	1	2	2	3	3
System Performance and Energy Yield (SPEY)	-	-	-	-	-	-
System Lifetime Costs (SLC)	1	1	1	2	3	3
Environmental and Social Acceptance (ESA)	1	1	1	2	3	3

The second way that the Deployment and Assessment tools and the Stage Gate module are linked is through the **Stage Gate Assessment** functionalities. The Stage Gate assessment functionalities include **Applicant Mode** and **Assessor Mode**, which are detailed in sections 3.2.3 and 3.2.4 respectively. As part of the Applicant Mode, the user will be required to answer qualitative and quantitative questions about their technology. The quantitative questions refer to a set of *key metrics* that can be calculated by the Deployment and Assessment tools. As shown in Figure 3-2, if the user has previously run the Deployment and Assessment tools, they can associate any previously obtained results with a Stage Gate assessment. Alternatively, within Applicant Mode the user will be presented with the option of opening the Deployment and Assessment tools and using them to calculate results for the key metrics.

3.1.2 INTEGRATION WITH STRUCTURED INNOVATION MODULE

As shown in Figure 3-3, a selection of the outputs of the Stage Gate module can be used in the Structured Innovation (SI) module. Similarly, the Structured Innovation module can provide certain parameters to the Stage Gate module if the user first completes an analysis using the SI module.

FIGURE 3-3: INTEGRATION OF THE STAGE GATE AND STRUCTURED INNOVATION MODULES

The parameters that SG will provide SI are:

- **Stage Gate** – an identification of the stage that a technology or device has reached (identified through the Activity Checklist functionality discussed previously and described in detail in section 3.2.2).
- **Metric results** – the key metric results provided by the users in response to the quantitative questions of a Stage Gate Assessment. Note that the SI module will also be able to retrieve these key metrics directly from the Deployment or Assessment tool where they originate. SG is also required to provide this list of results to enable the use case when the user has run SG, manually entered the results for the key metrics (see section 3.1.3 on Standalone mode) but has not run the Deployment and Assessment tools.
- **Metric thresholds** – a user can edit the *thresholds* for any of the key metrics in the Stage Gate Framework. This parameter consists of a list of any of the thresholds that the user has implemented (see section 3.2.1 on Stage Gate Frameworks).
- **Improvement areas** – the Stage Gate module may identify one or more *improvement areas* (see section 3.2.4). These improvement areas can be used by the SI module as the basis for a new *improvement cycle* analysis that enables innovation of an existing concept.

The parameters that SI will provide to SG are:

- **Targets** – the target values set by the user for the functional requirements of the SI module. In the QFD/TRIZ[2] component of the SI module, the user can set targets for each of the functional requirements. For example, they might set a target for capital cost that they want to achieve. This list of targets is required by the SG module to give the user the option of using the same targets as metric thresholds within a Stage Gate Framework.
- **Achievements** – a list of any achievements that the user previously inputted to the SI module. These achievements are specified by the user against the *targets* mentioned above. SG is requesting this list of achievements because there is some overlap between these values and the *metric results* of a Stage Gate assessment. For instance, consider that a user has already run an

[2] QFD is Quality Function Deployment, TRIZ is the Theory of Inventive Problem Solving.

analysis in the SI module and entered an achievement result for capital cost. If the user then opens the SG tool and comes to the quantitative question asking for the result for capital cost, it would be beneficial to have alongside the input box for the metric a list of the values achieved by the user in the corresponding study from the SI module.

3.1.3 STANDALONE MODE

The use case for the Stage Gate module in Standalone Mode is shown in Figure 3-4. The diagram shows the flow through the SG module when there is no integration with the other DTOceanPlus tools. The main difference in using the module in this manner is that users cannot use the Deployment and Assessment tools to calculate the results for the key metrics and must instead supply these inputs themselves.

The most logical flow through the SG module is as outlined in Figure 3-4, starting with the functionality for viewing the Stage Gate Framework data, moving onto the Activity Checklist, performing a Stage Gate assessment first in Applicant Mode and secondly in Assessor Mode, if applicable, before finally exporting the results in the form of a standardised report. However, the user is also able to open the Stage Gate module and use both the Activity Checklist and Stage Gate assessment functionalities immediately. Similarly, the standardised report can be generated after the user completes the Activity Checklist but before they perform a Stage Gate assessment.

Note that a Stage Gate assessment can be performed in Applicant Mode or Assessor Mode, but that Assessor Mode is only available if an analysis has first been completed using Applicant Mode. SG can compare the results of several analyses, but this requires two or more Stage Gate assessments to have been completed first. The next subsection describes in detail each of the individual functionalities shown in Figure 3-4.

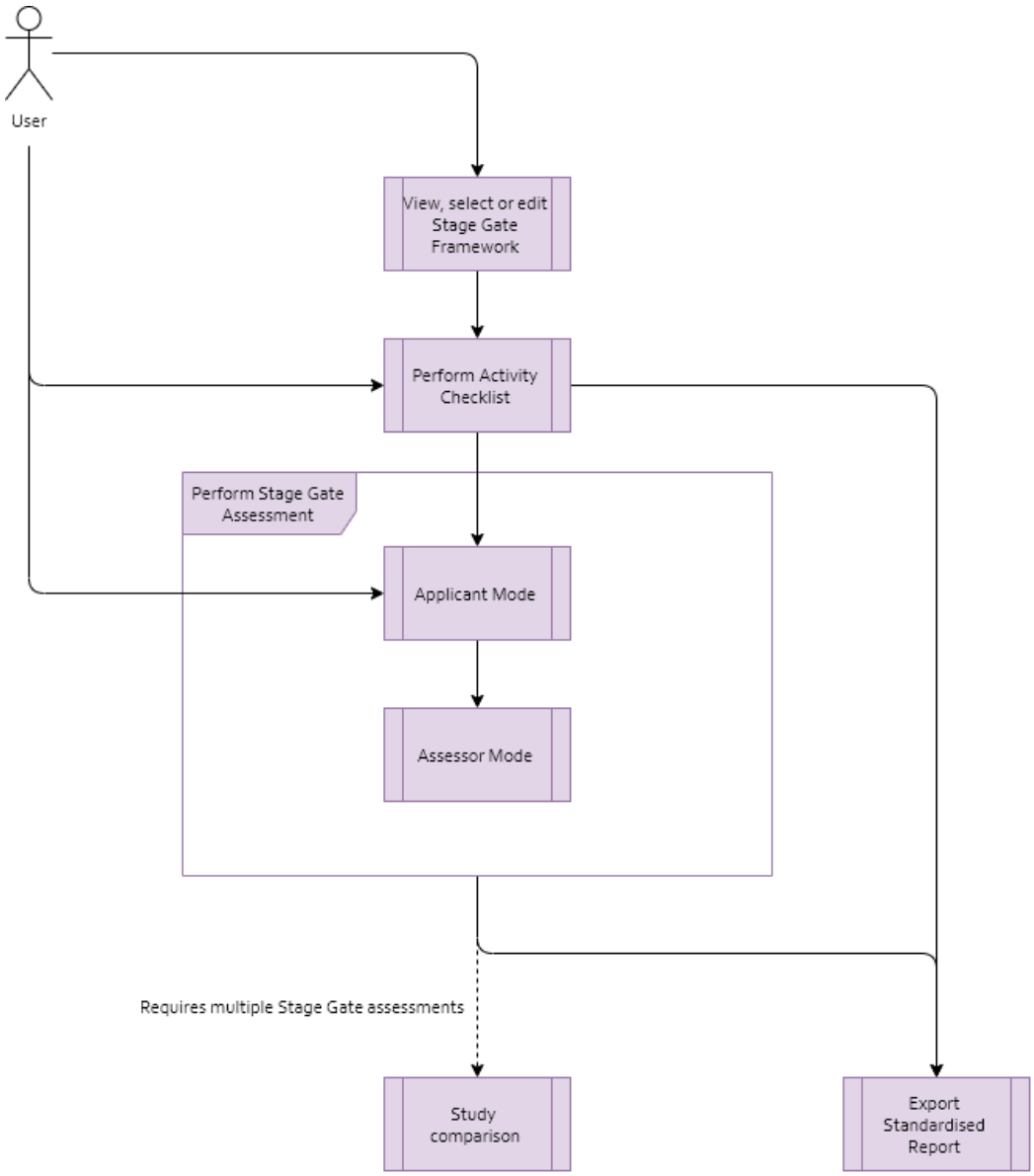


FIGURE 3-4: STANDALONE MODE OF THE STAGE GATE MODULE

3.2 THE FUNCTIONALITIES

The Stage Gate module has seven major functionalities:

1) **Stage Gate Framework** – functionality for viewing the Stage Activity and Stage Gate Question data of the Stage Gate Framework developed for DTOceanPlus. This functionality also enables the user to edit the Stage Gate Framework by specifying the metric thresholds that are applied.
2) **Activity Checklist** – allows the user to work through the required activities for each stage of the Stage Gate programme in turn and record whether they have been completed or not. This enables SG to identify the specific stage that a device or technology has reached.

3) **Applicant Mode** – the first component of the Stage Gate assessment functionality. Presents to the user a set of qualitative and quantitative questions about their technology that they must answer. Emulates the application process at the stage gate of a typical technology development programme, from the point of view of the *Applicant*.
4) **Assessor Mode** – the second component of the Stage Gate assessment functionality. Presents to the user the answers supplied by an *Applicant* in a previous Applicant Mode assessment and requests Assessor *scores* and *comments*. Emulates the assessment process of a Stage Gate of a typical technology development programme, from the point of view of the *Assessor*.
5) **Improvement Areas** – the methodology for identifying the improvement areas highlighted by a Stage Gate analysis. These refer to the characteristics of a device or technology that the SG module has identified as needing further development or refinement.
6) **Report Export Functionality** – generate a standardised report in PDF format that summarise all the key information associated with a Stage Gate analysis.
7) **Study Comparison** – compare the results of two or more Stage Gate Assessments that have been performed by the user.

Further details and key methods for each of these functionalities are given in the following sections.

3.2.1 STAGE GATE FRAMEWORK

The main purpose of the Stage Gate Framework functionality is to display the *stage activity* and S*tage Gate assessment* data defined in section 2. The *stage activity* data describe each of the activities that technology developers or innovators are expected to perform in successive stages of the programme. The S*tage Gate assessment* data contain a set of qualitative and quantitative questions for each stage gate in the programme. These questions emulate the typical application forms that innovators and developers must complete at each Stage Gate and that are used to evaluate the capabilities of the device and readiness to progress to the next stage of the programme.

Additionally, the user can edit the Stage Gate Framework by specifying the metric thresholds that are applied. This functionality is described fully in section 3.2.1.3. Note that copies of the framework can be created to allow users to save multiple versions of the framework, each with a different set of metric thresholds. These copies of the framework are identical apart from the metric thresholds that are applied. Funders, investors, policy-makers and regulators are the user groups that are most likely to edit the metric thresholds, as shown in Figure 3-1.

3.2.1.1 STAGE ACTIVITY DATA

To ensure clear presentation of the data, the stage activities can be categorised by either evaluation area (see section 2.2) or what is known as an *activity category*. An activity category is used to group similar activities under a common technical task. Some examples are listed in Table 3-2.

TABLE 3-2: EXAMPLE ACTIVITY CATEGORIES

Stage	Activity	Activity Category	Evaluation Areas
3	Develop complete installation plan	Installation plan	Installability
3	Independent review of installation plan	Installation plan	Installability
3	Open-water testing of device	Open-water testing	▫ Reliability ▫ Installability ▫ Survivability ▫ Availability ▫ Energy Capture
3	Practical demonstration of installation plan	Open-water testing	Installability

As can be seen in Table 3-2, an activity can be linked to more than one evaluation area. However, an activity can only be categorised under a single activity category.

3.2.1.2 STAGE GATE ASSESSMENT DATA

In a similar manner to the activity data, the Stage Gate assessment data consists of a set of question categories, with each category containing a list of questions. Unlike the stage activity data, the question data cannot be categorised by evaluation area. The presentation of the Stage Gate question data is intended to replicate an application form of a Stage Gate and thus the order and structure of the questions is considered important.

Individual questions can be one of two types: qualitative and quantitative. Qualitative questions expect a single response to be entered by the user. Quantitative questions are linked to the key metrics that the user can choose to calculate using the Deployment and Assessment tools. For each quantitative question, the user is expected to provide the answer for the metric result as well as a written justification of how they calculated the metric and/or the assumptions underlying the calculation.

Each question is also associated with a set of scoring criteria. These scoring criteria tell the user what the assessors will be looking for when evaluating the responses and justifications. Additionally, each question has a percentage weighting, showing its relative importance in the Stage Gate assessment. These weightings are used when the aggregated assessor scores are being calculated. More details on both the scoring criteria and the question weightings are given in the section on the **Assessor Mode** (section 3.2.4).

3.2.1.3 METRIC THRESHOLDS

The other major purpose of the Stage Gate Framework functionality is to enable the user to edit the *metric thresholds* that are being applied in the Stage Gate Assessment. For each of the quantitative questions, the user can set a threshold that they are hoping to achieve. Depending on the metric, the threshold can be one of two types: 'upper' or 'lower', referring to whether the threshold is an upper or lower limit. More information on the evaluation procedure or both types is given in section 3.2.3.

By default, there will be no metric thresholds applied for a new Stage Gate analysis. This is because it is difficult to derive a general set of thresholds that apply in every circumstance. Depending on the application, project location and objectives of the technology development programme or project, the thresholds may vary substantially.

If the user does set any thresholds in the Stage Gate Framework functionality, these limits can be passed to the Structured Innovation module as a service, as outlined in Figure 3-3 and section 3.1.2.

3.2.2 ACTIVITY CHECKLIST

The Activity Checklist functionality presents the *stage activity* data to the user, allowing them to browse through successive activities and stages and mark those activities that have been completed. As with the **Stage Gate Framework** functionality, the activity data can be categorised by either *activity category* or *evaluation area*.

Once the user submits their responses, the Activity Checklist functionality assesses the number of activities completed and uses the answers to identify the appropriate stage gate that the user is ready to be assessed against. The percentage of activities completed at each stage is calculated by dividing the number of completed activities by the total number of activities in that stage. Within each stage, additional calculations are performed that calculate percentage values for the number of activities completed for each activity category and evaluation area. The general formula that is used is

$$p_{cac} = 100 \times \frac{n_{cac}}{N_{ac}} \quad (1)$$

where

p_{cac} = percentage of completed activities in a category,
n_{cac} = number of completed activities in a category and
N_{ac} = number of activities in a category.

The category can be either a stage, an activity category or an evaluation area. The figure for completed activities is rounded to the nearest integer percentage.

The Activity Checklist functionality also compiles a list of the *outstanding activities* that are yet to be completed and displays them to the user. This helps to show the remaining tasks that the user must complete before being considered ready for the next Stage Gate. These outstanding activities can be categorised by either evaluation area or activity category.

Finally, the Activity Checklist functionality also identifies the suggested Stage Gate that they should be assessed against. This informs the user of the suggested Stage Gate that they should be assessed against. The appropriate stage and Stage Gate are selected by identifying the latest successive stage, starting from Stage 0, that has reached 100% completion.

3.2.3 APPLICANT MODE

Applicant Mode is the mandatory first step in a Stage Gate assessment that presents a set of qualitative questions to the user for a specified Stage Gate. As mentioned previously, a question can be either qualitative or quantitative. Qualitative questions expect a single response to be entered by

the user. Quantitative questions require the user to provide both the metric result as well as a written justification of their methods and/or assumptions. The applicant answers are saved by the Stage Gate module once the user submits their responses.

3.2.3.1 ASSESSING QUANTIATIVE QUESTIONS

In the case where a user has set metric thresholds, the first procedure implemented in Applicant Mode is the assessment of whether the metric results submitted by the user have *passed* or *failed* the thresholds. As mentioned in section 3.2.1.3, a threshold can either be an 'upper' or a 'lower' type threshold. An 'upper' threshold refers to an upper limit. A user's answer for a metric result with an upper limit will only succeed if the value is lower than the limit. Conversely, a 'lower' threshold refers to a lower limit. A user's answer for a metric result with a lower limit will only succeed if the value is greater than the limit. For example, the *Levelised Cost of Energy (LCOE)* metric is an 'upper' type. If the user sets a threshold for LCOE of 150 Euro/MWh, then this metric will only be 'passed' if an answer lower than this is achieved. The capacity factor metric is an example of a 'lower' type. A user will only succeed in 'passing' a 20% capacity factor threshold if a value greater than 20 is achieved.

For each quantitative question with an applied metric threshold, Applicant Mode assesses whether the metric result provided by the user leads to a *pass* or a *fail* result, accounting for the two types of threshold mentioned above.

In addition to asserting the pass/fail status of the applicable quantitative questions, two additional parameters are calculated; the *absolute difference* and the *percent difference*. These parameters refer to the difference between the metric result and the metric threshold. The formulae for calculating the two parameters are

$$d_a = |m_r - m_t| \tag{2}$$

and

$$d_p = 100 \times \frac{d_a}{m_t} \tag{3}$$

where

d_a = absolute difference,
d_p = percent difference,
m_r = metric result and
m_t = metric threshold.

The unit of the *absolute difference* parameter is the same as the unit of the associated metric. The unit of the *percent difference* parameter is a percentage value, rounded to the nearest integer.

3.2.3.2 CALCULATING SUMMARY RESULTS

Once any quantitative questions with an applied metric threshold have been analysed, the Applicant Mode functionality calculates the summary results; the *response rate* and the *threshold success rate*. They are calculated as follows:

$$r_r = 100 \times \frac{n_{aq}}{N_q} \tag{4}$$

and

$$r_t = 100 \times \frac{n_{pm}}{N_{qt}} \quad (5)$$

where

r_r = response rate,
r_t = threshold success rate,
n_{aq} = number of answered questions,
N_q = total number of questions,
n_{pm} = number of metric results that have *passed* and
N_{qt} = number of questions with metric thresholds applied.

A qualitative question is *answered* when the applicant has provided a *response*. A quantitative question is *answered* when both the *metric result* and *justification* have been input by the user.

3.2.3.3 METRIC RESULTS SERVICE

If requested by the Structured Innovation module, a list of any metric results inputted by the user and saved by the SG module can be provided.

3.2.4 ASSESSOR MODE

Assessor Mode is the optional second step in a Stage Gate assessment. The user is presented with the answers that were provided in a previous Applicant Mode study. For each question the response or result and justification are also displayed. The user in this case (the "Assessor") is requested to provide a *score* and *comments* on each question and corresponding applicant answer.

3.2.4.1 ASSESSOR SCORES AND COMMENTS

The *assessor score* must be selected from rubric shown in Table 3-3 below. This is based on the 5-point scale used frequently by Wave Energy Scotland in their Stage Gate assessments.

TABLE 3-3: RUBRIC FOR ASSESSOR SCORES

Score	Label	Description
0	Unacceptable	Nil or inadequate response which fails to demonstrate an ability to meet the requirements
1	Poor	Response is partially relevant but generally poor. It addresses some elements of the requirements but contains insufficient/limited detail or explanation to demonstrate how the requirement will be fulfilled
2	Acceptable	Response is relevant and acceptable. It addresses a broad understanding of the requirement but may lack details on how the requirement will be fulfilled in certain areas
3	Good	Response is relevant and good. It is sufficiently detailed to demonstrate a good understanding and provides details on how the requirements will be fulfilled
4	Excellent	Response is completely relevant and excellent overall. It is comprehensive, unambiguous and demonstrates a thorough understanding of the requirement and provides details of how the requirement will be met in full

As mentioned in section 3.2.1.2, each question is also associated with a set of scoring criteria. A question can have one or more scoring criteria. In Assessor Mode, the user can provide a comment for each scoring criterion of a question. Each comment should describe the user's assessment of the applicant's answer in relation to that scoring criterion and considering the scoring system detailed above.

The user must provide a score and comments for every question in the Stage Gate Assessment. The assessor scores and comments are saved by the Stage Gate module once the user submits their responses.

3.2.4.2 CALCULATING AVERAGE ASSESSOR SCORES

As mentioned in section 3.2.1.2, each question in a Stage Gate assessment has a weighting. The weightings are *relative*, meaning that the weightings are expressed as decimal numbers between 0 and 1, and for a single Stage Gate, the weightings sum to 1. The Assessor Mode calculates average and weighted average scores using these weightings and the scores provided by the user in the assessment. Average and weighted average scores are calculated for the overall assessment as well as for the scores categorised by

- Question Categories and
- Evaluation Areas.

Note that an average and weighted average score can be calculated for each evaluation area because of the link between the quantitative questions and the evaluation areas. A quantitative question is directly linked to a single metric. In turn, this metric is related to a single evaluation area.

The overall average score is calculated as the arithmetic mean of all the raw assessor scores for a stage gate. Similarly, the average score for each Question Category and Evaluation Area is calculated as the arithmetic mean of all the scores for questions in that sub-category:

$$\bar{s_c} = \frac{1}{N_{qc}} \sum_{i=1}^{n} s_{c,i} \tag{6}$$

where

$\bar{s_c}$ = the average assessor score for a category,
N_{qc} = the number of questions in a category and
$s_{c,i} = s_1, s_2, \ldots s_n$ = the assessor scores for questions in a category.

The category can be either a stage gate, a question category or an evaluation area.

For the weighted average parameters, the weighted scores are first obtained by multiplying the assessor score by the weighting of each question. The overall weighted average is then calculated as the sum of the weighted scores. This is possible because the weightings are *relative*, as discussed above:

$$\overline{s_w} = \sum_{i=1}^{n} s_i \times w_{q,i} \quad (7)$$

where

$\overline{s_w}$ = the overall weighted average score for the Stage Gate,
$s_i = s_1, s_2, \ldots, s_n$ = the assessor scores for questions in a Stage Gate and
$w_{q,i} = w_1, w_2, \ldots, w_n$ = the relative weightings of the Stage Gate questions.

The weighted average for a single category (evaluation area or question category) is calculated by summing the weighted scores for that category and dividing this total by the sum of the weightings for that category. This is equivalent to dividing the total weighted score for the category by the total possible weighted score for that category and multiplying the resulting ratio by the highest score in the rubric.

$$\overline{s_{w,c}} = \frac{\sum_{i=1}^{n} s_{c,i} \times w_{qc,i}}{\sum_{i=1}^{n} w_{qc,i}} \quad (8)$$

where

$\overline{s_{w,c}}$ = the weighted average score for a category,
$s_{c,i}$ = the assessor scores for questions in a category and
$w_{qc,i}$ = the relative weightings for the questions in a category.

3.2.5 IMPROVEMENT AREAS

The Stage Gate module can also identify *improvement areas* that can be passed to the Structured Innovation module as discussed previously and illustrated in Figure 3-3. The improvement areas are specific Evaluation Areas that have been identified as being weaknesses of the device or technology. The SG module identifies these improvement areas using three methods. Specifically, an Evaluation Area will be marked as an improvement area if:

1) less than 50% of the activities for a specific Evaluation Area in a Stage Gate were marked *complete* by the user,
2) the result provided by the user for a metric tagged to an Evaluation Area fails to meet the previously specified threshold or
3) an assessor score of less than or equal to 2 was given to an applicant's response tagged to an Evaluation Area.

The above methods are applied to each Evaluation Area in turn, noting any of the improvement area causes. As an example, for the *Affordability* evaluation area, if the user:

- only marked 40% of answers as complete;
- supplied metric results for two metrics tagged to *Affordability* that did not pass the applied thresholds and
- received an assessor score of 1 for both the Stage Gate questions that correspond to these two metrics, then the SG module would identify five causes for this specific Evaluation Area and example.

The list of identified improvement areas (if there are any) is then ordered by the number of causes in descending order. This ranked list of improvement areas is provided to the SI module as a service, as discussed previously and shown in Figure 3-3. Note that the improvement areas can be obtained if an analysis has been performed using one of either the **Activity Checklist** or **Stage Gate Assessment** functionalities. For instance, if a user has run the Activity Checklist for a technology but not the Stage Gate assessment, a user of the SI module can still get the improvement areas, but they will only have been informed by the first cause as described above.

3.2.6 REPORT EXPORT FUNCTIONALITY

All the data provided by the user and calculated by the SG module can be formatted as a standardised report. This report can be downloaded as a PDF file using the GUI of the SG module.

As shown in Figure 3-4, the report can be generated after completing any of the main functionalities; Activity Checklist, Applicant Mode or Assessor Mode. In other words, the user does not need to complete all the functionalities provided by the SG module to be able to generate a PDF report.

The aim of the report is to standardise the presentation of the Stage Gate data in a clear and consistent manner. This will enable technology developers and innovators to obtain clear, succinct summaries of the stage that they have reached, the outstanding stage activities and the improvement areas that they need to address. For funders, investors, policy-makers and regulators, a standardised format for presentation of results for the Stage Gate programme will facilitate comparisons between technologies.

3.2.7 STUDY COMPARISON

The user will have the option of comparing the summary results of two or more completed SG analyses. SG can compare applicant mode analysis results to other applicant mode results; and assessor mode results to other assessor mode results. All the results that have been discussed in the preceding sections can be compared across studies. Both graphical and tabular comparisons can be made.

For funders, investors, policy-makers and regulators, the Study Comparison functionality is a dynamic and interactive method of comparing two or more technologies or devices. For technology and project developers, the comparison functionality can be used to compare various iterations of their device or technology. Similarly, users can create a benchmark analysis study and use this as the basis of any future comparisons. In each use case, the objective is to facilitate a clear and concise comparison of the Stage Gate analysis results.

4. THE IMPLEMENTATION

4.1 THE ARCHITECTURE OF THE TOOL

Each module of the DTOceanPlus suite of design tools was organised in three layers:

- The Business Logic, including a set of modules, classes and libraries for implementing the functionalities of the modules.
- The Application Programming Interface (API) that represents the connection between the modules as well as the connection between the Business Logic and the Graphical User Interface. The SG module will mainly consume services from the Deployment and Assessment modules. It will provide metrics to SI as shown in Figure 3-3.
- The Graphical User Interface (GUI) which enables interaction with the user, collects inputs from the users, displays results and enables data to be imported and exported.

4.1.1 BUSINESS LOGIC

A simplified Unified Modelling Language (UML) diagram for the Stage Gate Business Logic is shown below in Figure 4-1. Most of the key functionalities described in Section 3.2 can be seen in the UML diagram. Each of the components will be discussed in detail in the subsequent sections.

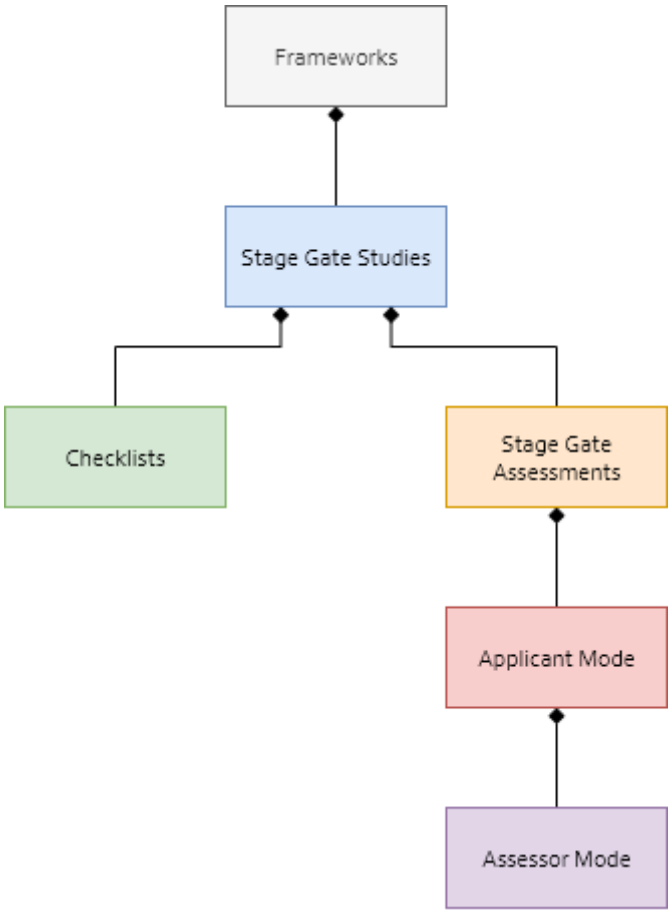


FIGURE 4-1: SIMPLIFIED UML DIAGRAM FOR STAGE GATE MODULE

The diagram highlights the importance of the *Framework* resource. As will be discussed in the subsequent sections, a *Stage Gate Study* cannot exist without a link to an existing *Framework*. Subsequently, the *Activity Checklist* and *Stage Gate Assessment* functionalities cannot be used without first creating a *Stage Gate Study*. Finally, a *Stage Gate Assessment* must first be completed in *Applicant Mode* before the *Assessor Mode* is enabled.

4.1.1.1 SQLITE DATABASE

An SQLite database was developed to implement the local storage system for the Stage Gate module. This database, implemented using the ***SQLAlchemy*** Python package, is used to store all the input and output data associated with the Stage Gate tool. In addition to the SQLite database, the Python package ***marshmallow*** is used for serialization and de-serialization (in the case of DTOceanPlus, this refers to methods that convert Python data objects to *JSON* format and vice versa). ***marshmallow*** is also used to perform validation of data-flow in the back-end. All the SQLite database table classes are stored in a ***models.py*** file in the business logic folder. Similarly, all the ***marshmallow*** schemas can be found in the ***schemas.py*** file.

4.1.1.2 FRAMEWORKS

The *Framework* component stores the critical Stage Gate Framework data, which includes both the Stage Activity data and the Stage Gate question data. This is also the resource that allows users to set metric thresholds for the quantitative questions included in a Stage Gate Assessment.

A UML Class diagram for the Frameworks component is given in Figure 4-2. Each of the classes in this diagram corresponds to an ***SQLAlchemy*** database model. Note that there are also classes for evaluation areas and metrics as well as rubrics and grades that can exist independently from the main *framework* class.

A ***frameworks.py*** python script has also been developed for the Business Logic. This contains several functions that are not shown in the class diagram below. Included in this list of additional functions are methods

- used by the API-layer for CRUD operations (Create, Read, Update and Delete operations) for the Frameworks resource,
- for setting the value of the metric thresholds,
- for retrieving a list of the metric thresholds that have been set (this constitutes one of the services provided to SI, see section 3.1.2) and
- categorising the activities for a stage by evaluation area rather than activity category.

4.1.1.3 STAGE GATE STUDIES

The Stage Gate Studies component implements the main architecture of the SG module. Multiple Stage Gate studies can be created, each corresponding to a new analysis. When a new study is created, the user must specify which Framework they want to apply to the new analysis. As such, a

Stage Gate Study cannot exist without a pre-defined Framework.

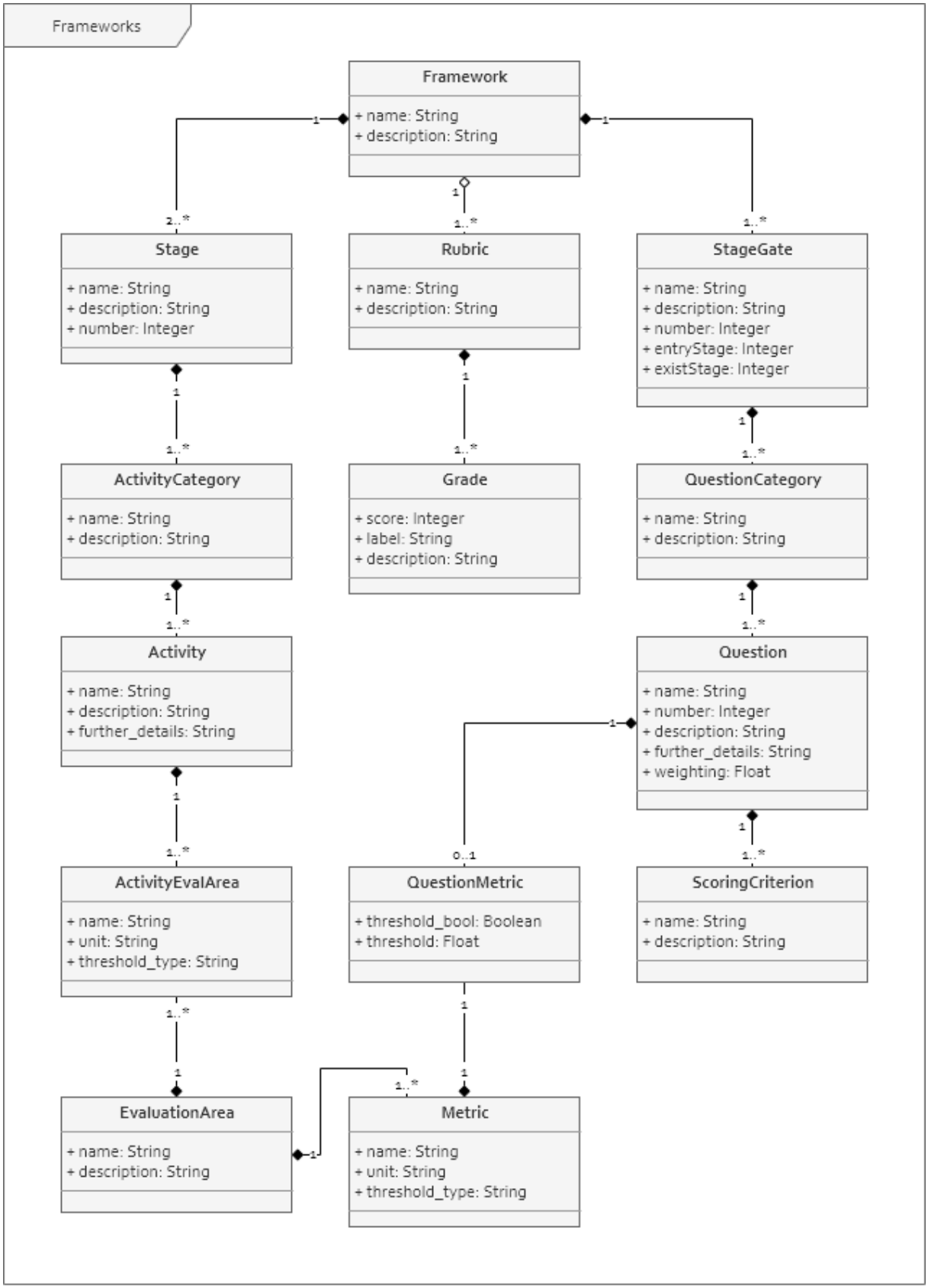


FIGURE 4-2: UML CLASS DIAGRAM FOR FRAMEWORKS RESOURCE

Every time a new study is created, the SG module needs to create several additional database tables to store the inputs and outputs for that specific study. In the ***stage_gate_studies.py*** python file, there is a ***StageGateFamily*** class that is used to create these additional database tables. This python file also includes functions for implementing CRUD operations for the *Stage Gate Studies* resource.

The *Stage Gate Studies* resource also contains three more classes; ***ImprovementAreas***, ***ReportExport*** and ***StudyComparison***. These implement the functionalities described in sections 3.2.5, 3.2.6 and 3.2.7 respectively.

4.1.1.4 ACTIVITY CHECKLIST

To implement the Activity Checklist functionality, an SQLAlchemy database table named ***ChecklistActivity*** is added that extends the ***Activity*** class from the Frameworks resource. This is shown in Figure 4-3. This structure avoids duplication of data objects for studies that use the same framework.

A key component of the Activity Checklist that is not shown in Figure 4-3 is the function that updates the *'complete'* property of the ***ChecklistActivity*** class. This function takes the list of activities marked as *'complete'* by the user in the GUI and updates the status of the corresponding database table properties.

The ***ChecklistResults*** class and related classes enable the analysis of the Activity Checklist inputs. Specifically, they implement the functionality summarised by equation (1), which yields one of the major outputs of this resource (the percentage number of activities completed for each stage in the framework) which in turn yields the suggested Stage Gate that the user should be assessed against.

4.1.1.5 APPLICANT MODE

The UML Class diagram for the *Applicant Mode* resource is shown in Figure 4-4. The ***ApplicantAnswer*** class extends the ***Question*** class from the Frameworks resource. This database table stores the results, justifications and responses given by the user to each of the questions in a Stage Gate Assessment. A function that is not shown in the Class diagram, ***update_applicant_answers_in_db***, is used to update the Applicant Answers in the local storage database.

The ***ThresholdAnalysis*** class assesses the metric results provided by the user, evaluating the metric results against any previously set metric thresholds. If a metric threshold has been applied, then the class calculates the absolute and relative differences between the thresholds and results using equations (2) and (3).

The ***ApplicantAnswerAnalysis*** class assesses whether each of the questions have been fully answered or not. As discussed in section 3.2.3.2, the *answered* property of a qualitative question is marked as *True* if a response has been provided by the user, while the *answered* property of a quantitative question is set as *True* if both a result and a justification are given.

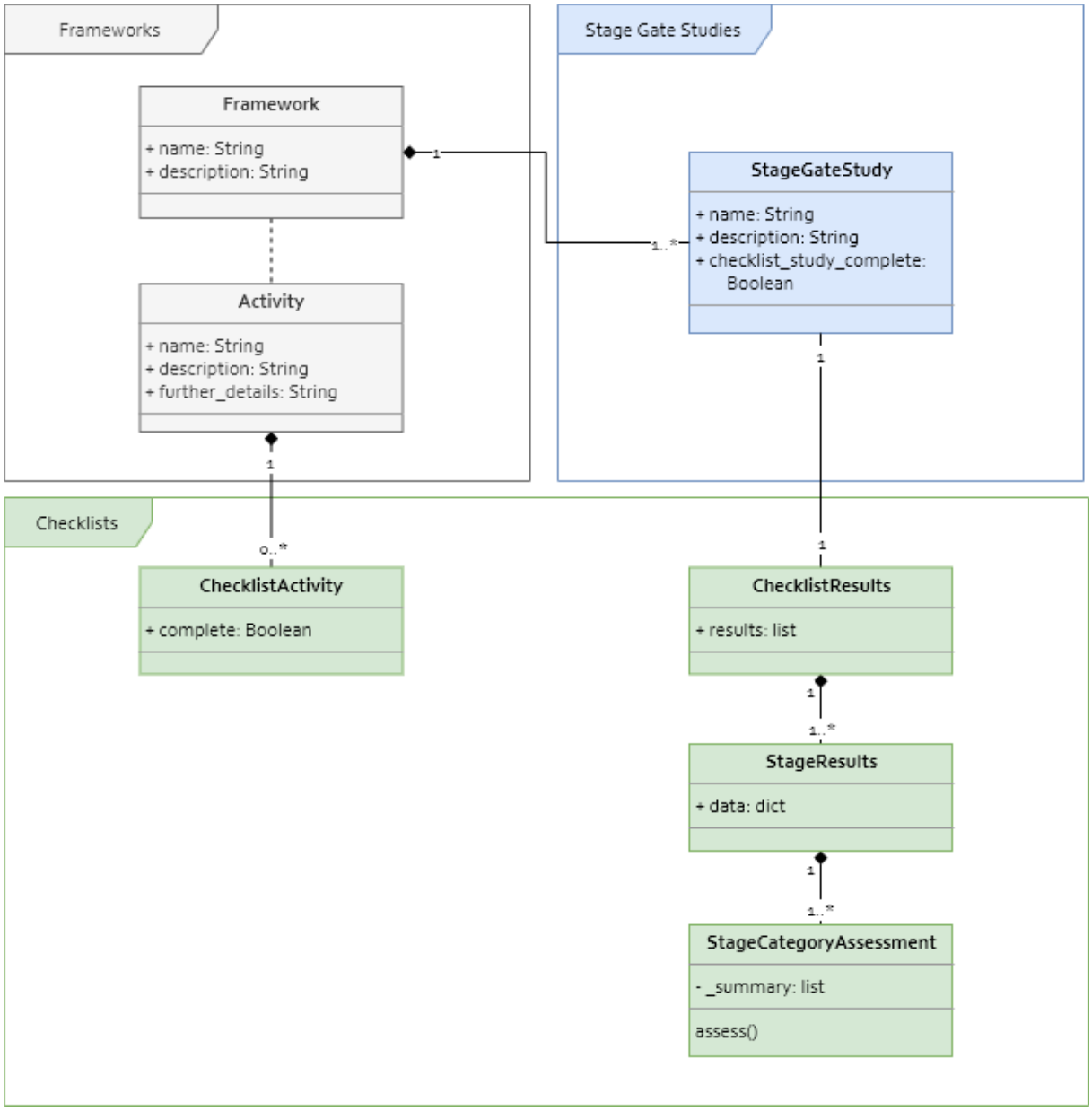


FIGURE 4-3: UML CLASS DIAGRAM FOR ACTIVITY CHECKLISTS RESOURCE

Finally, the ***ApplicantResults*** class collates the results and calculates the summary *response rate* and *threshold success rate* parameters detailed in equations (4) and (5).

Note that the ***ApplicantResults*** class requires another class named ***ApplicantStageGateData*** that is used to convert the Stage Gate question data to the nested format required for the front-end.

The *applicant_complete* property of the ***StageGateAssessment*** class is set to *True* once a user submits their responses to a Stage Gate Assessment. An *Assessor Mode* study can only commence once this property is set to *True*.

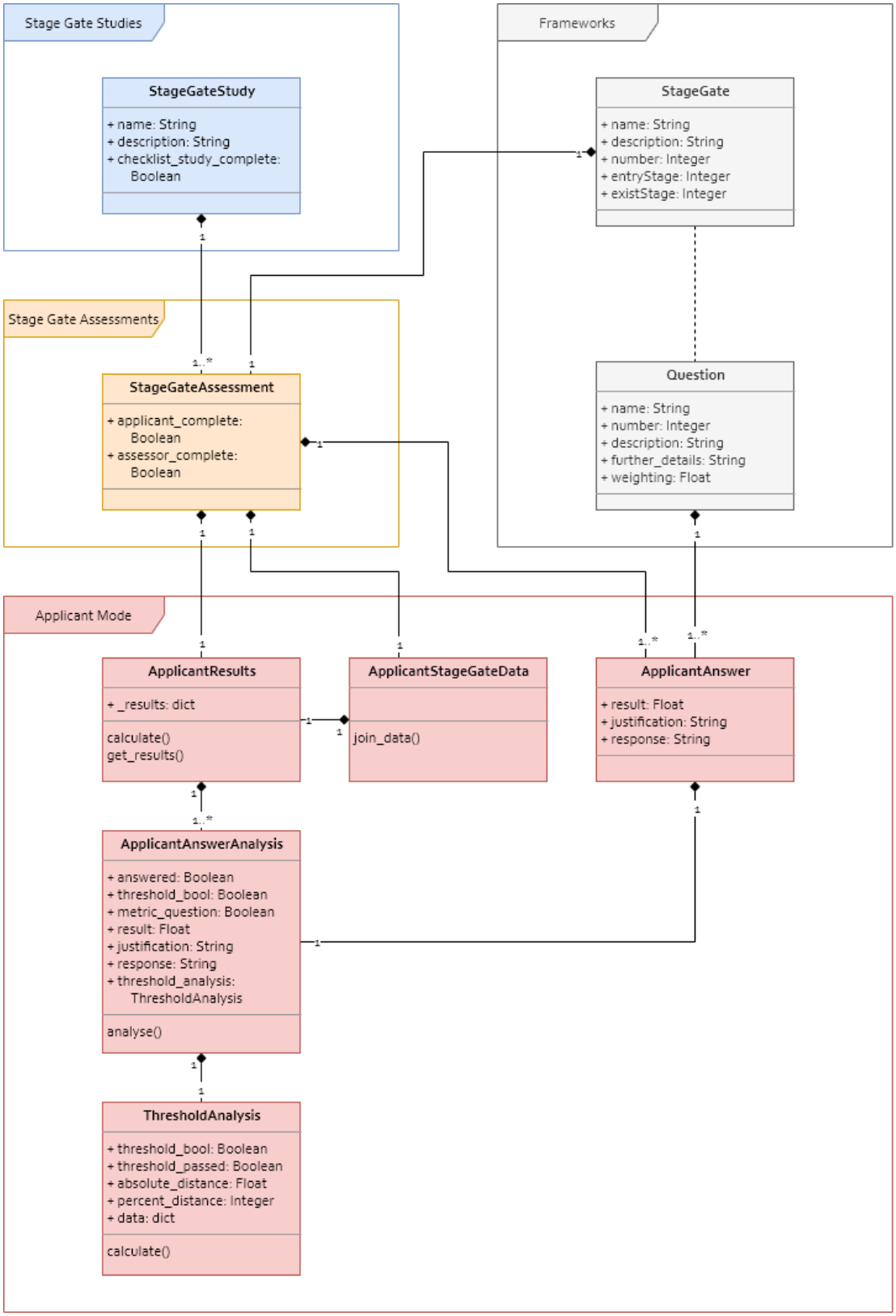


FIGURE 4-4: UML CLASS DIAGRAM FOR THE APPLICANT MODE RESOURCE

4.1.1.6 ASSESSOR MODE

A UML Class diagram for the *Assessor Mode* component is given in Figure 4-5. This diagram shows that the ***AssessorScore*** and ***AssessorComment*** classes extend the ***Question*** and ***ScoringCriterion*** classes from the Framework resource. These classes save the scores and comments provided by the user in the local storage for SG. There are equivalent functions for updating the appropriate database tables that are not shown in the UML diagram.

The ***AssessorResults*** class is where the average and weighted average calculations summarised in equations (6) – (8) are implemented in the code. As with the *Applicant Mode* resource, the ***AssessorStageGateData*** class is required to format the assessor stage gate data in the correct structure required by the front-end.

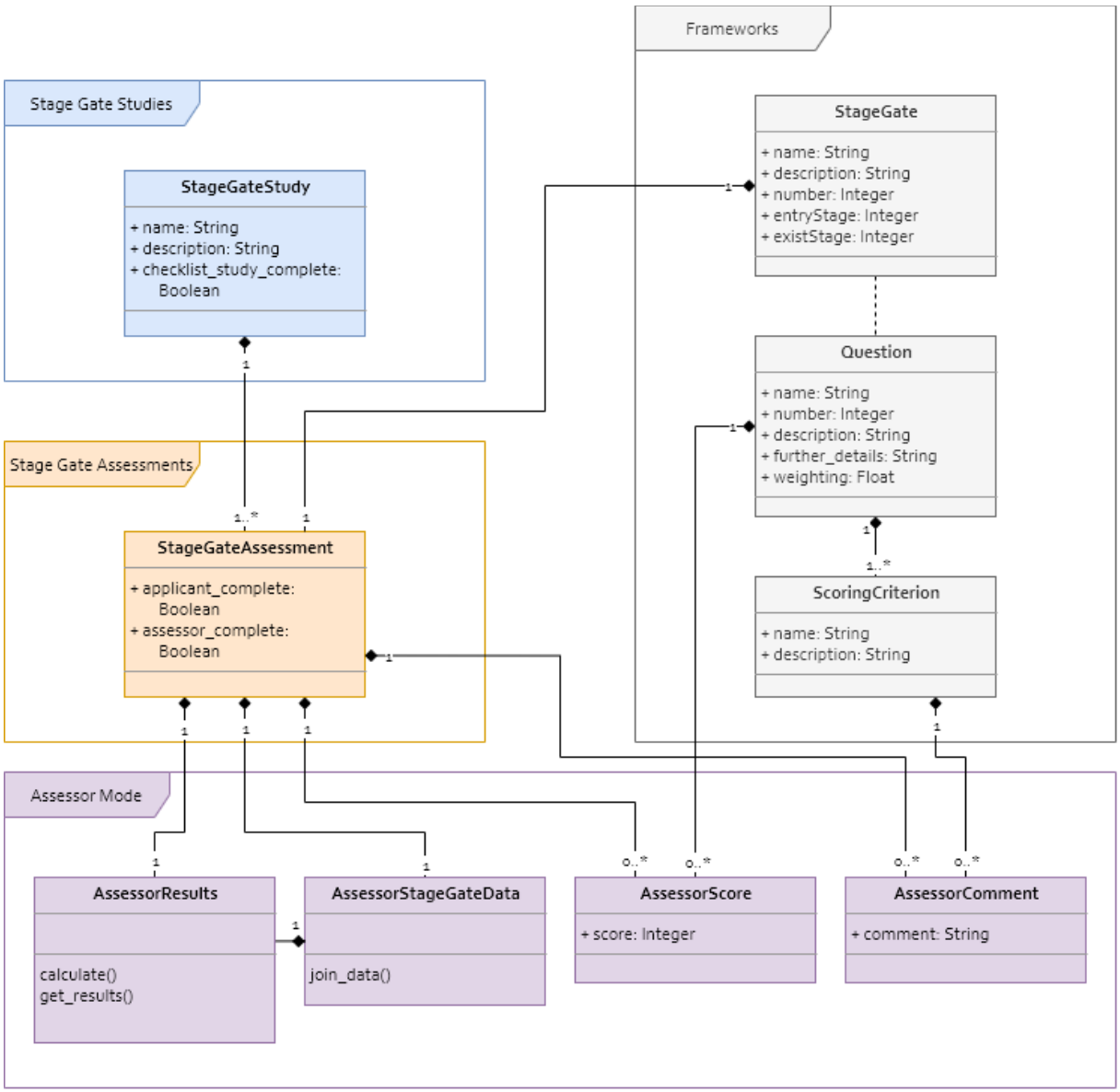


FIGURE 4-5: UML CLASS DIAGRAM FOR THE ASSESSOR MODE RESOURCE

4.1.2 API

As with each of the DTOceanPlus modules, SG is following the representational state transfer (REST) approach for its API and uses HyperText Transfer Protocol (HTTP) as the transport protocol. The OpenAPI-Specification (OAS3) format was used when developing the API.

An OpenAPI file was created that describes both the internal and external interfaces for the Stage Gate module. The internal interface refers to the routes and resources that enable the connection between the Business Logic and the GUI of the Stage Gate tool. The external interface refers to the public services that are available for other modules to consume.

The full API describing both internal and external interfaces is available as part of the code documentation. Below, the public services that will be consumed by other modules are listed as well as the routes for CRUD operations for the *Stage Gate Studies* resource that are included to give examples of the routes that have been implemented.

4.1.2.1 PUBLIC SERVICES

- **GET > /api/frameworks/{frameworkId}/metric-thresholds**- List the metric thresholds entered by a user for a Stage Gate framework
- **GET > /api/stage-gate-assessments/{appSgId}/applicant-results** – List the Applicant Results, containing the metric results entered by the user in Applicant Mode
- **GET > /api/stage-gate-studies/{sgId}/improvement-areas** – List the improvement areas that have been highlighted in a Stage Gate study
- **GET > /api/stage-gate-studies/{sgId}/complexity-levels** – List the evaluated stage, stage gate and corresponding complexity levels identified by a Stage Gate study

4.1.2.2 STAGE GATE STUDY ROUTES

- **GET > /api/stage-gate-studies** – Returns a list of the available Stage Gate Studies
- **POST > /api/stage-gate-studies** – Create a new Stage Gate Study
- **GET > /api/stage-gate-studies/{sgId}** – Read a single Stage Gate Study
- **PUT > /api/stage-gate-studies/{sgId}** – Update a Stage Gate Study
- **DELETE > /api/stage-gate-studies/{sgId}** – Delete a Stage Gate Study

4.1.2.3 FLASK AND DREDD

The back-end of the SG module, which implements the routes described in the OpenAPI file, has been developed using the Python package ***Flask***. The API and its ***Flask*** implementation have been validated using ***Dredd***, the HTTP API Testing Framework.

4.1.3 GUI

The GUI layer for the Stage Gate module has been developed using ***Vue.js***, the JavaScript framework. ***Element***, which is a Vue 2.0 based component library, is being used by all the DTOceanPlus modules to ensure a consistent visual theme.

Each of the main Business Logic components that have been described in sections 4.1.1.2 - 4.1.1.6 has a corresponding Vue.js ***view*** in the GUI-layer of the code.

Example screenshots taken from the Stage Gate GUI are included in section 5 of this report.

4.1.4 THE TECHNOLOGIES

The Business Logic and the API of SG were coded in Python version 3.6.9. The installation of the module requires the following non-standard Python packages:

- Flask
- flask-babel
- flask-cors
- flask-sqlalchemy
- flask-marshmallow
- Pandas
- requests
- pytest

The API was developed using the OpenAPI specification v3.0.2.

The GUI of the module was developed using Vue.js, using the Element component library.

Code documentation for the Business Logic and the back-end implementation of the API has been written using ***reStructuredText*** (reST) and ***Sphinx***, the Python documentation generator. The documentation is available in PDF format in the ***docs*** folder of the Stage Gate tool source code. This will eventually be included in the technical manual for DTOceanPlus.

4.2 TESTING AND VERIFICATION

The ***pytest*** framework was used to implement unit testing for the business logic and the back-end. Unit tests verify that each line of code that has been written is functioning as intended. A coverage of 100% has been reached for both the business logic and the back-end of the Stage Gate tool. A HTML version of the coverage report that is produced by ***pytest*** is available in the ***htmlcov*** folder of the Stage Gate source code. A screenshot of the summary page of this coverage report is shown in Figure 4-6.

Front-end tests have been written for the *Frameworks*, *Stage Gate Studies* and *Activity Checklist* components. Furthermore, end-to-end tests (E2E) that verify the *full-stack* (business logic, back-end and front-end) have been written for the *Frameworks* and *Stage Gate Studies* components.

Coverage report: 100%

Module ↓	statements	missing	excluded	coverage
src\dtop_stagegate__init__.py	0	0	0	100%
src\dtop_stagegate\business__init__.py	0	0	0	100%
src\dtop_stagegate\business\applicant_mode.py	179	0	0	100%
src\dtop_stagegate\business\assessor_mode.py	113	0	0	100%
src\dtop_stagegate\business\checklists.py	108	0	0	100%
src\dtop_stagegate\business\db_utils.py	42	0	0	100%
src\dtop_stagegate\business\frameworks.py	97	0	0	100%
src\dtop_stagegate\business\models.py	158	0	0	100%
src\dtop_stagegate\business\schemas.py	143	0	0	100%
src\dtop_stagegate\business\stage_gate_studies.py	85	0	0	100%
src\dtop_stagegate\service__init__.py	42	0	0	100%
src\dtop_stagegate\service\api__init__.py	16	0	0	100%
src\dtop_stagegate\service\api\applicant_mode__init__.py	43	0	0	100%
src\dtop_stagegate\service\api\assessor_mode__init__.py	54	0	0	100%
src\dtop_stagegate\service\api\doc__init__.py	5	0	0	100%
src\dtop_stagegate\service\api\errors.py	13	0	0	100%
src\dtop_stagegate\service\api\frameworks__init__.py	99	0	0	100%
src\dtop_stagegate\service\api\stage_gate_studies__init__.py	100	0	0	100%
src\dtop_stagegate\service\api\utils.py	3	0	0	100%
Total	**1300**	**0**	**0**	**100%**

coverage.py v4.5.4, created at 2020-03-18 17:16

FIGURE 4-6: SCREENSHOT OF UNIT TESTING COVERAGE REPORT

5. EXAMPLES

In this section, an example is given for each of the Framework, Activity Checklist, Applicant Mode and Assessor Mode components. For each component, the scenario is described, and screenshots of the inputs and results pages of the SG tool are provided. Please note the inputs that are used are for illustrative purposes only and do not correspond to any specific project or technology. Note also that the GUI is not yet finalised, but the following screenshots show the main components of the tool as well as the process that will be consistent with the final version of the software.

5.1 STAGE GATE FRAMEWORK

The purpose of this example is to show how the Stage Gate Framework data is presented and how it is divided into Stages, with a corresponding set of Activities, and Stage Gates, with a corresponding set of Questions. The screenshots show how the user can browse through the Stage Gate Framework data. As such, this example is not divided into *Inputs* and *Results* sections.

As shown in Figure 5-1, the main page shows how the framework is made up of Stages and Stage Gates, as well as describing the summary details of the framework. The user can use the navigation bar to browse through the Stages and Stage Gates.

Figure 5-2 and Figure 5-3 show how the stage activity data is presented. The activity categories are presented as a summary of the types of activities that need to be completed (Figure 5-2). Each of the activity categories can be expanded to see the activities involved in each category. Similarly, each individual activity can be expanded or collapsed (Figure 5-3). Note that several of the activity descriptions are longer and more descriptive than the examples shown in Figure 5-3. See section A in the Annex for the full list of activity descriptions.

The activities can also be categorised by *Evaluation Area* using the switch button at the top of the page, as shown in Figure 5-4.

Finally, Figure 5-5 shows how the Stage Gate tabs present the question data in a similar fashion, with the questions separated into various question categories.

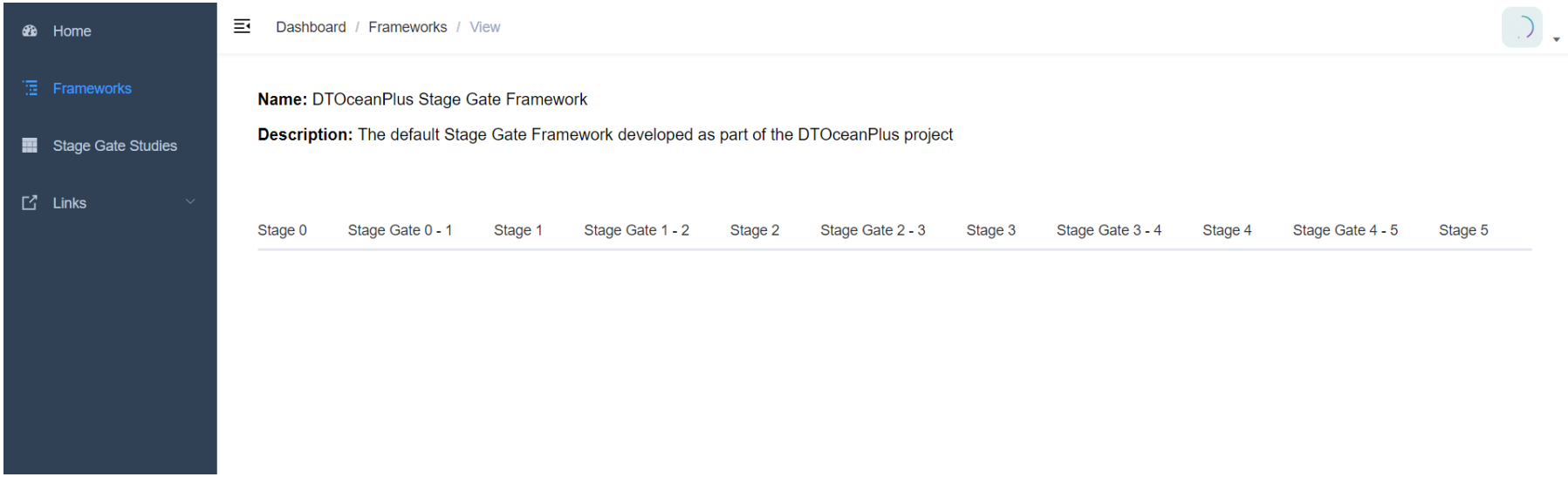


FIGURE 5-1: FRAMEWORK HOME PAGE

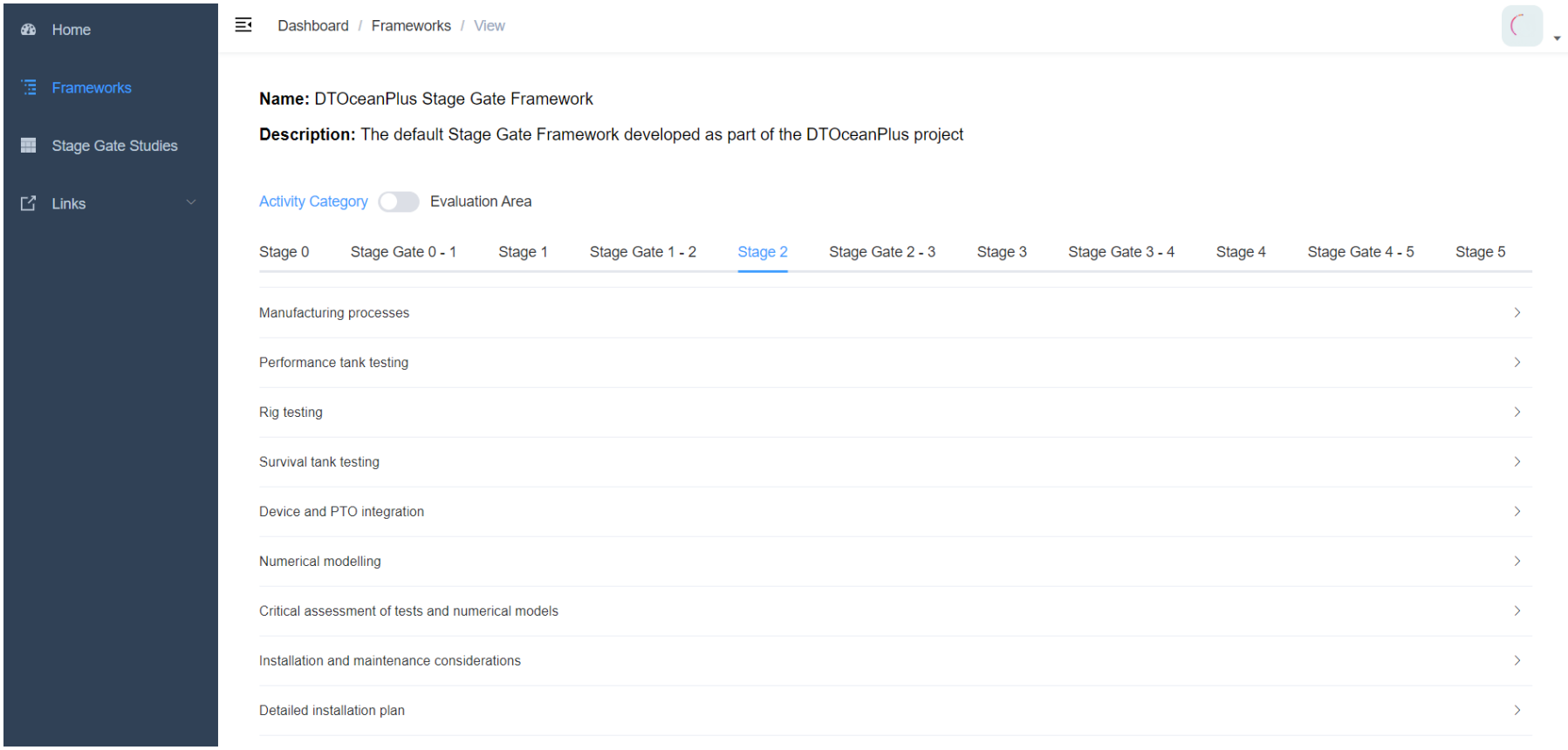


FIGURE 5-2: STAGE DATA SHOWING ACTIVITY CATEGORIES

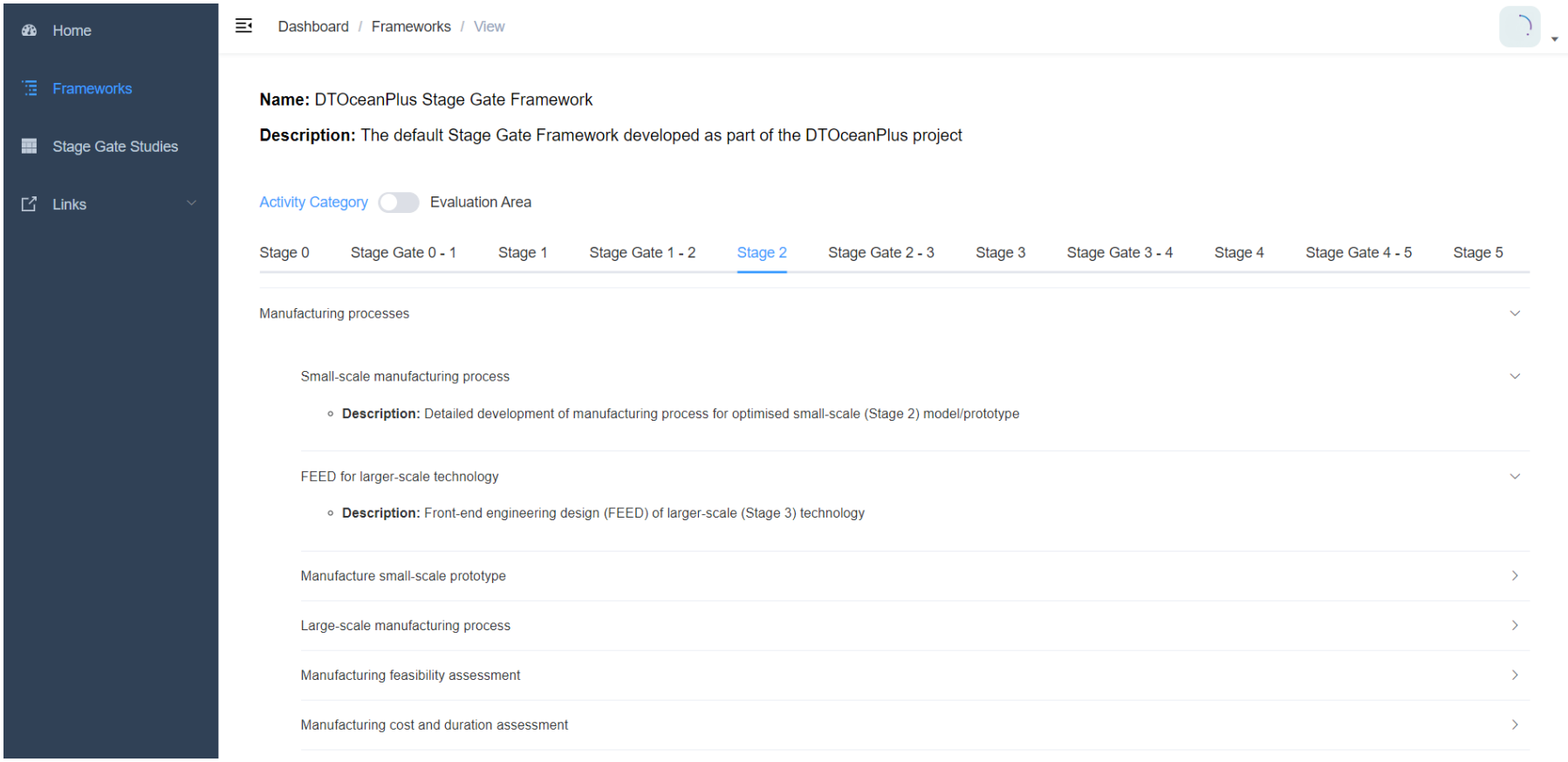


FIGURE 5-3: STAGE DATA SHOWING EXPANDED ACTIVITIES

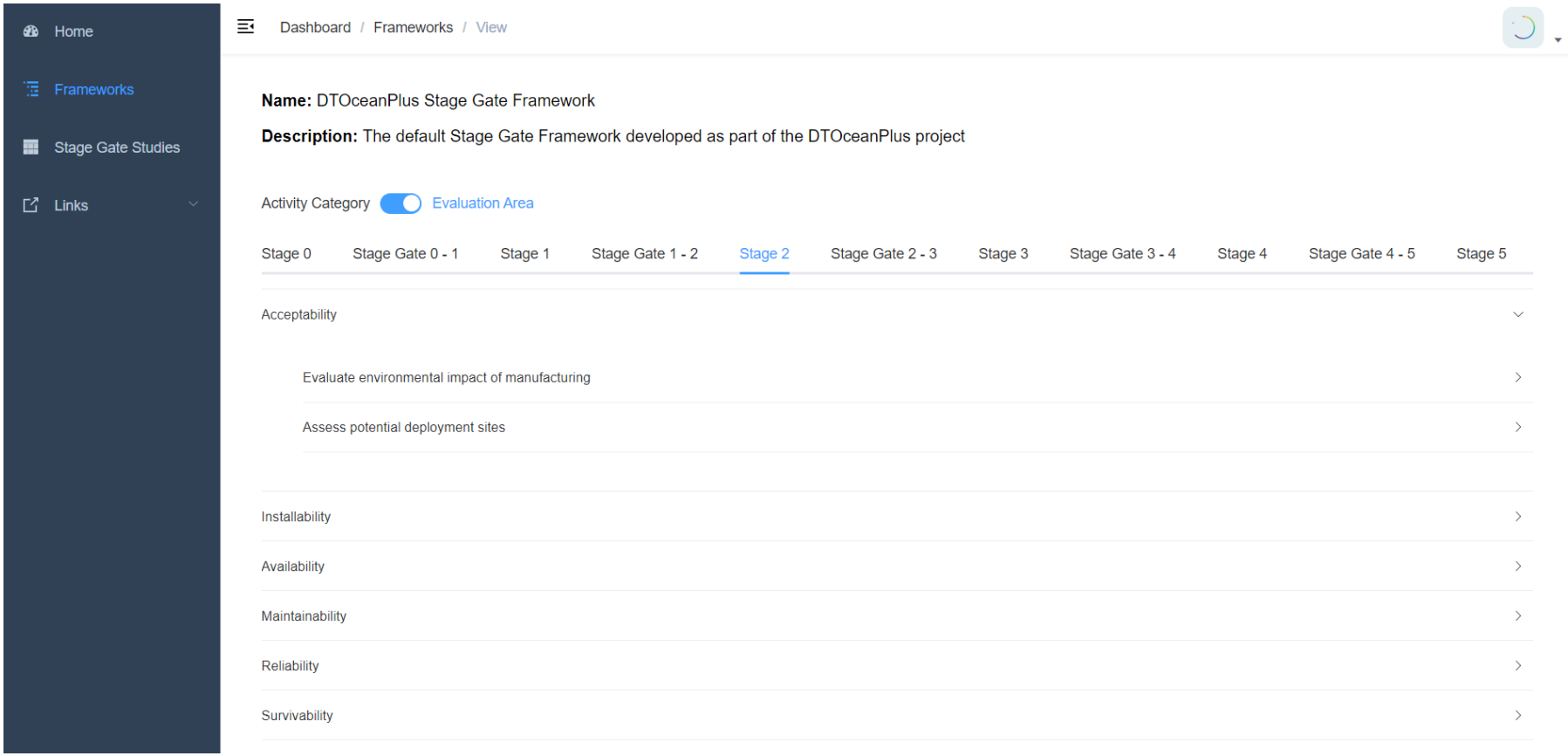


FIGURE 5-4: STAGE DATA CATEGORISED BY EVALUATION AREA

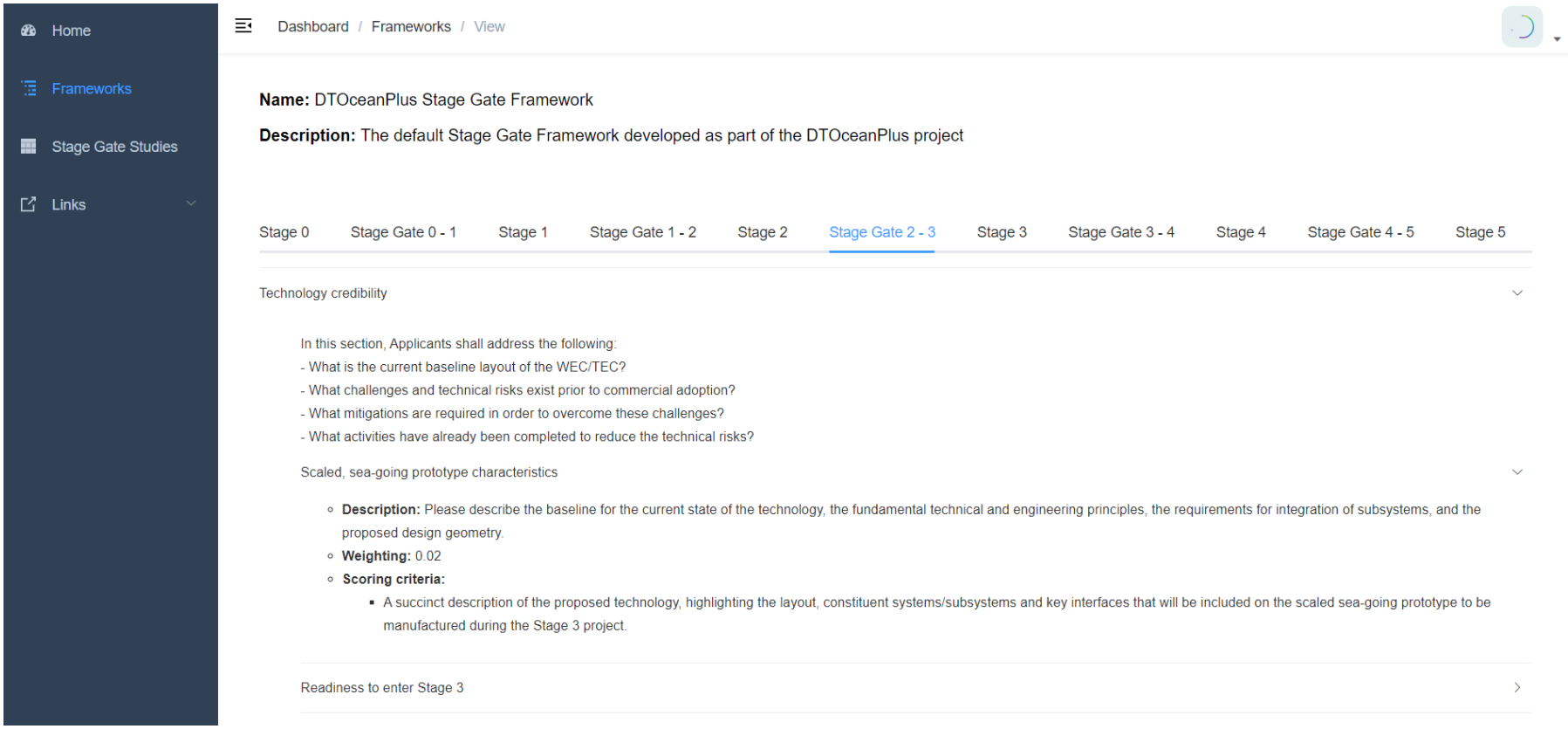


FIGURE 5-5: STAGE GATE QUESTION DATA

5.2 ACTIVITY CHECKLIST

5.2.1 INPUTS

The input page for the Activity Checklist component is shown in Figure 5-6 and Figure 5-7. This shows the same information that is presented in the *Frameworks* component with activity categories, the list of activities and the ability to categorise by Evaluation Area. The difference is that the user must now cycle through the Stages using the 'Previous Stage' and 'Next Stage' buttons. As they work their way through the stages, they need to mark the activities they have completed by selecting the 'Complete?' tick-box, as shown in Figure 5-7. They can finalise the data input procedure by pressing the 'Finish' button.

5.2.2 RESULTS

The main results page shows a summary of the percentage activities complete for each stage in the framework. An example of this is given in Figure 5-8.

More information can be obtained by clicking into any of the stages. This leads to the results page for the individual stage (see Figure 5-9) which shows the breakdown of percentage activities complete for both *activity categories* and *evaluation areas*. The results page also shows the outstanding activities that the user has not yet completed for the stage, which can also be categorised by Evaluation Area or Activity Category. This is shown in Figure 5-10.

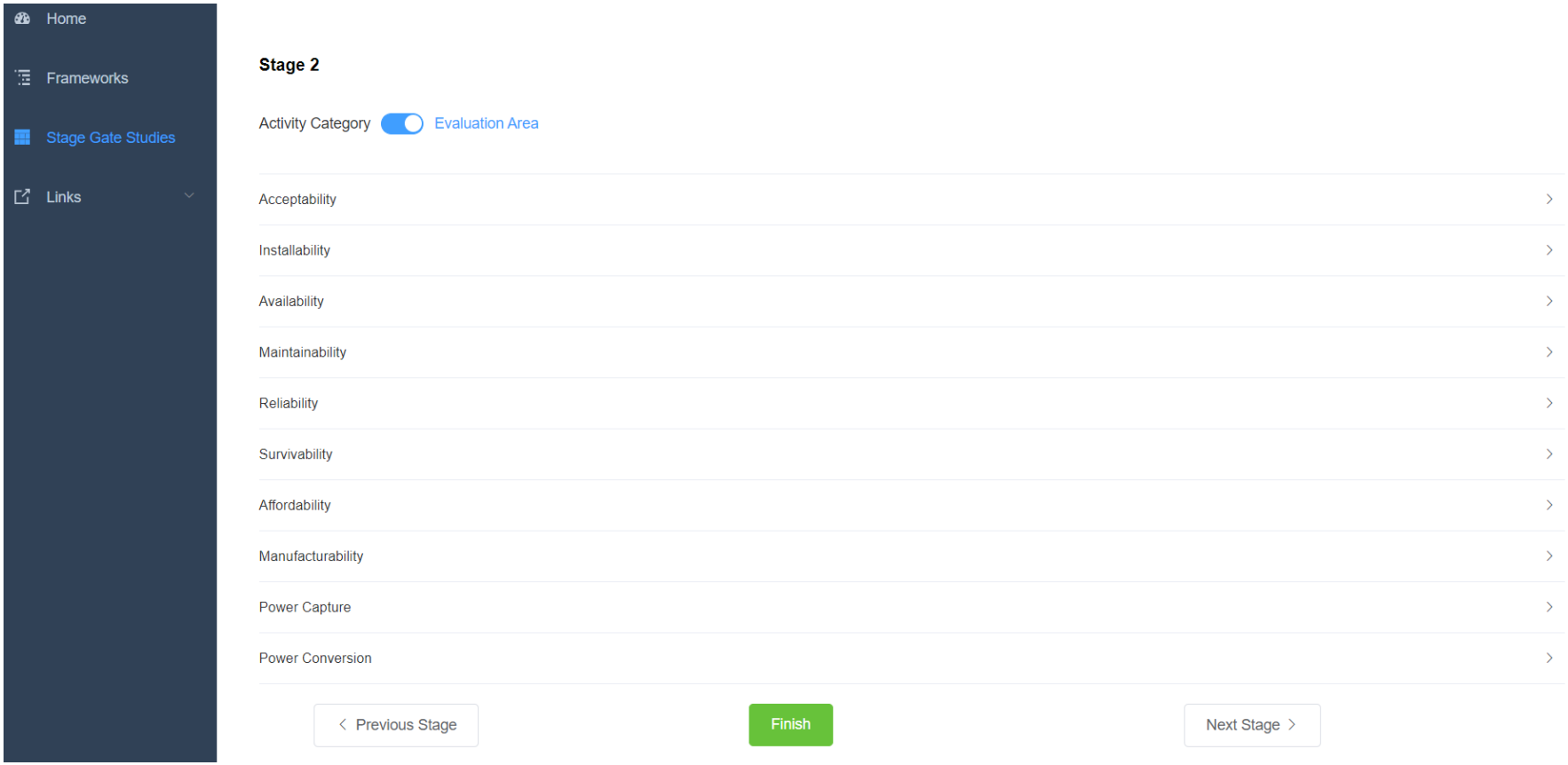


FIGURE 5-6: ACTIVITY CHECKLIST INPUT PAGE (I)

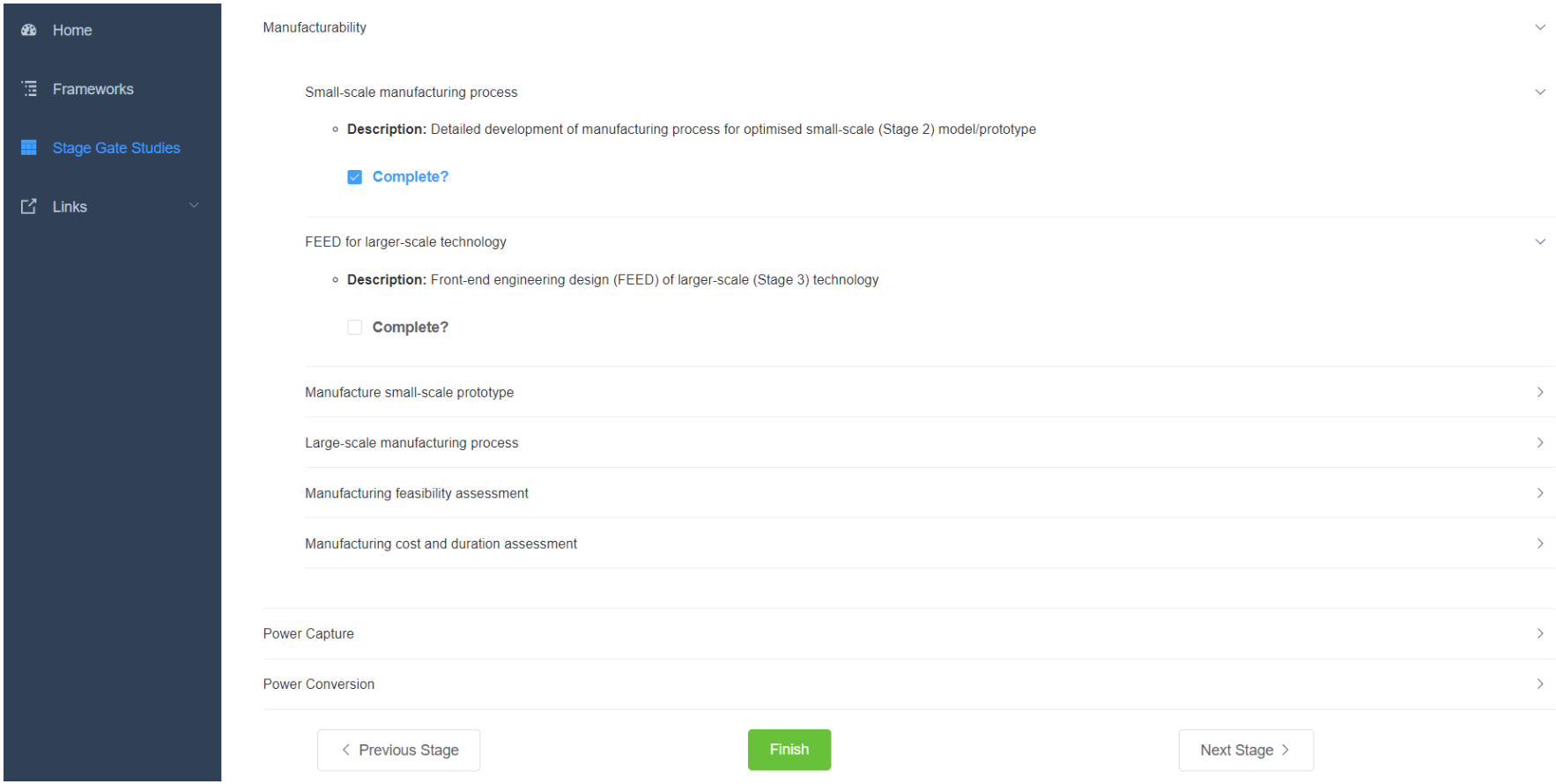


FIGURE 5-7: ACTIVITY CHECKLIST INPUT PAGE (II)

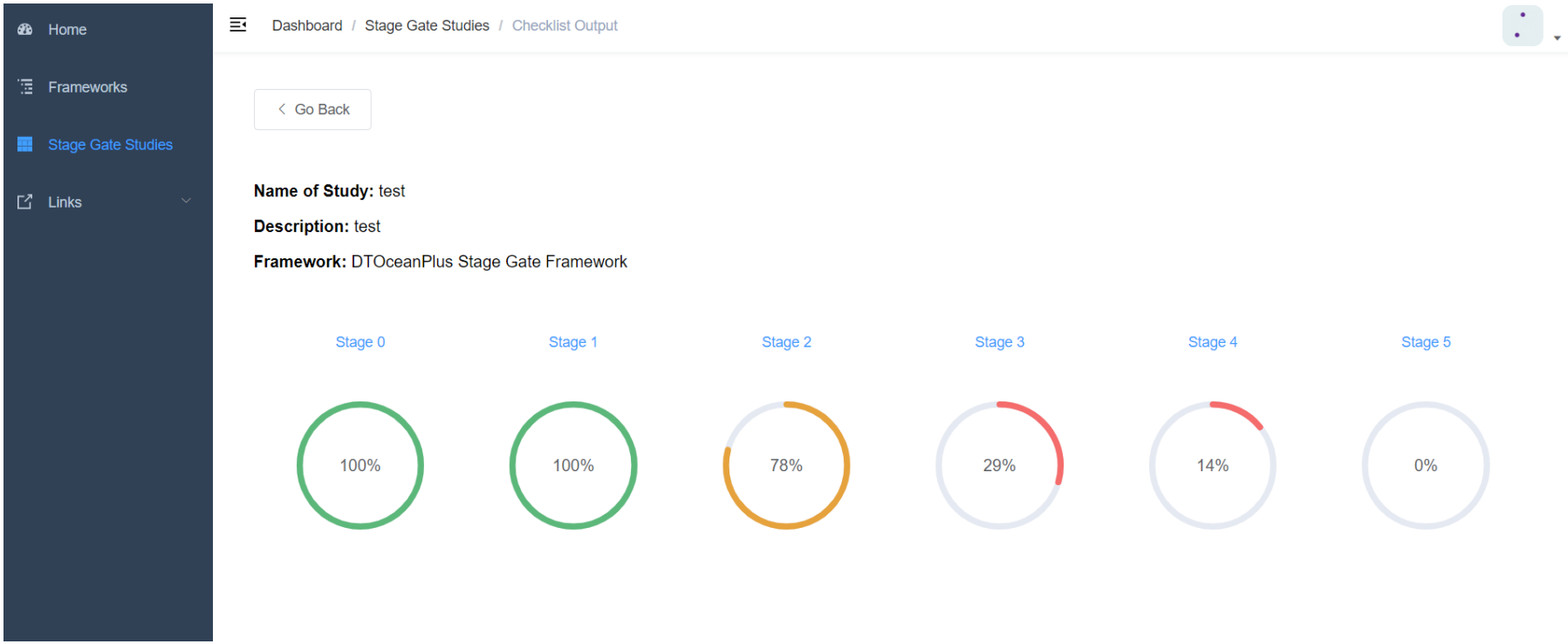


FIGURE 5-8: ACTIVITY CHECKLIST MAIN OUTPUT PAGE

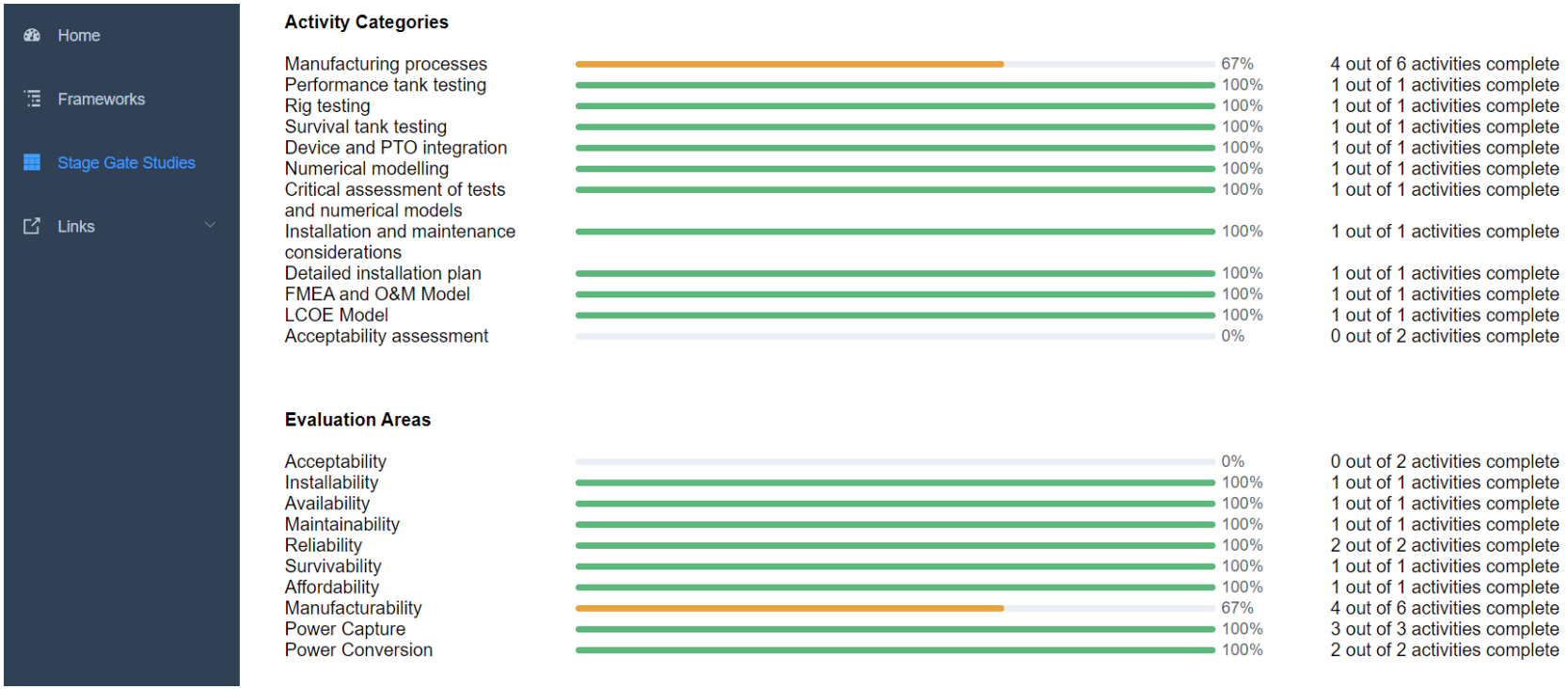


FIGURE 5-9: ACTIVITY CHECKLIST OUTPUT PAGE FOR A SINGLE STAGE

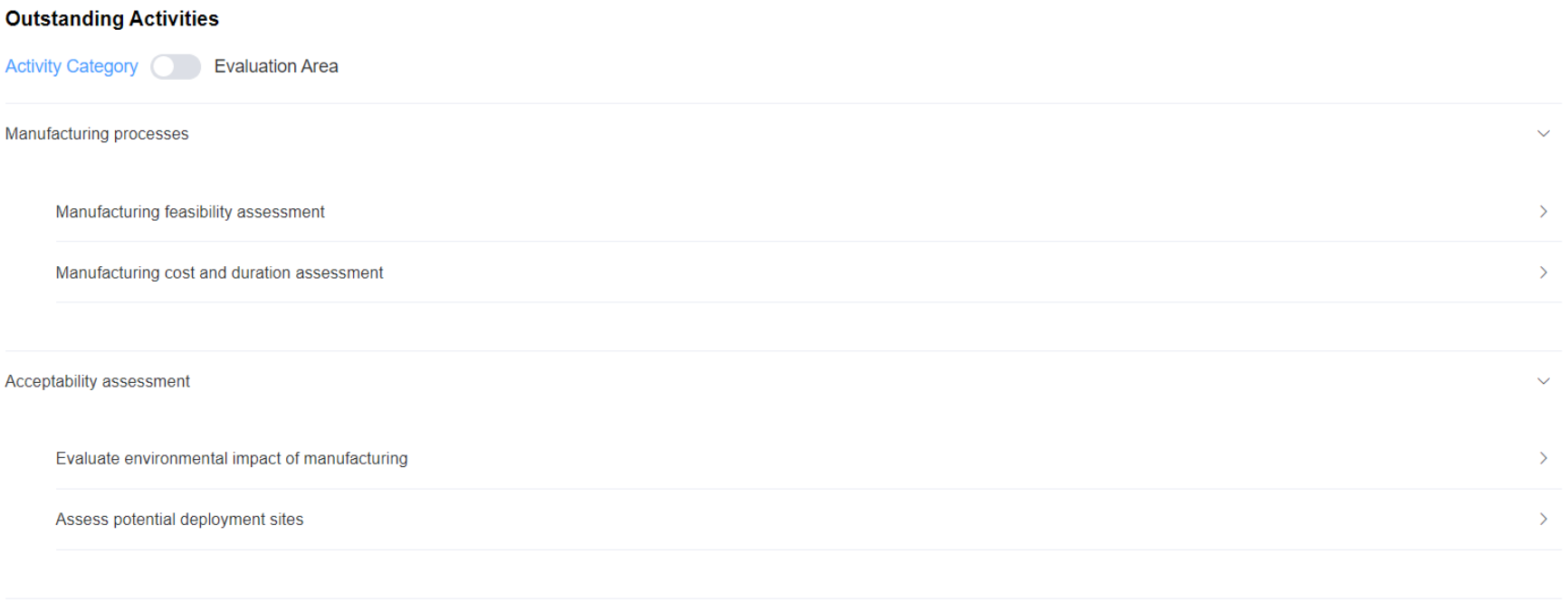


FIGURE 5-10: ACTIVITY CHECKLIST OUTSTANDING ACTIVITIES EXAMPLE

5.3 APPLICANT MODE

5.3.1 INPUTS

The inputs page for the *Applicant Mode* component is shown in Figure 5-11 and Figure 5-12. Again, this is similar to the presentation of the question data that is shown in the Framework component, but with the addition of user input boxes for the response or result and justification for each question. Figure 5-11 shows a quantitative question that requires a result and justification to be provided. Figure 5-12 shows a qualitative question that requires a response to be provided.

5.3.2 RESULTS

The Applicant Mode results page is divided into Summary, Metric Results and Responses sections, as shown in Figure 5-13. The Summary section shows the response rate and threshold success rate that are calculated based on the inputs provided by the user. The Metric Results section tabulates the metric results provided by the user (or calculated using the Deployment and Assessment tools), along with an indication of whether any results passed or failed their thresholds and the absolute and percentage differences between metric thresholds and results. The Responses section presents the responses to each question under the various question categories.

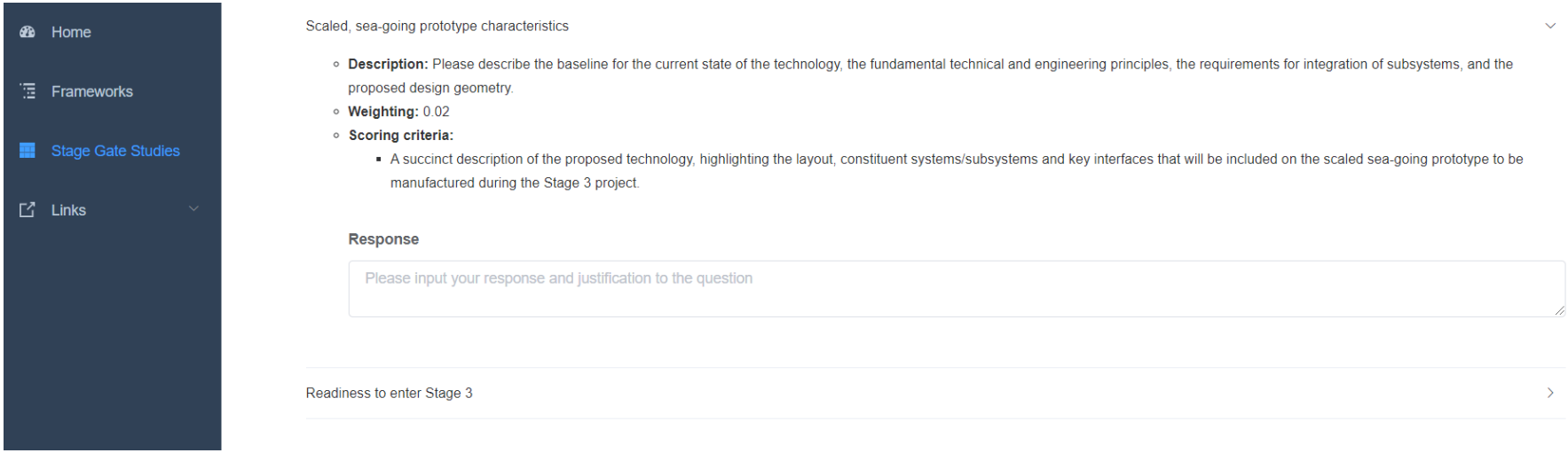


FIGURE 5-11: APPLICANT MODE INPUT PAGE - QUALITATIVE QUESTION

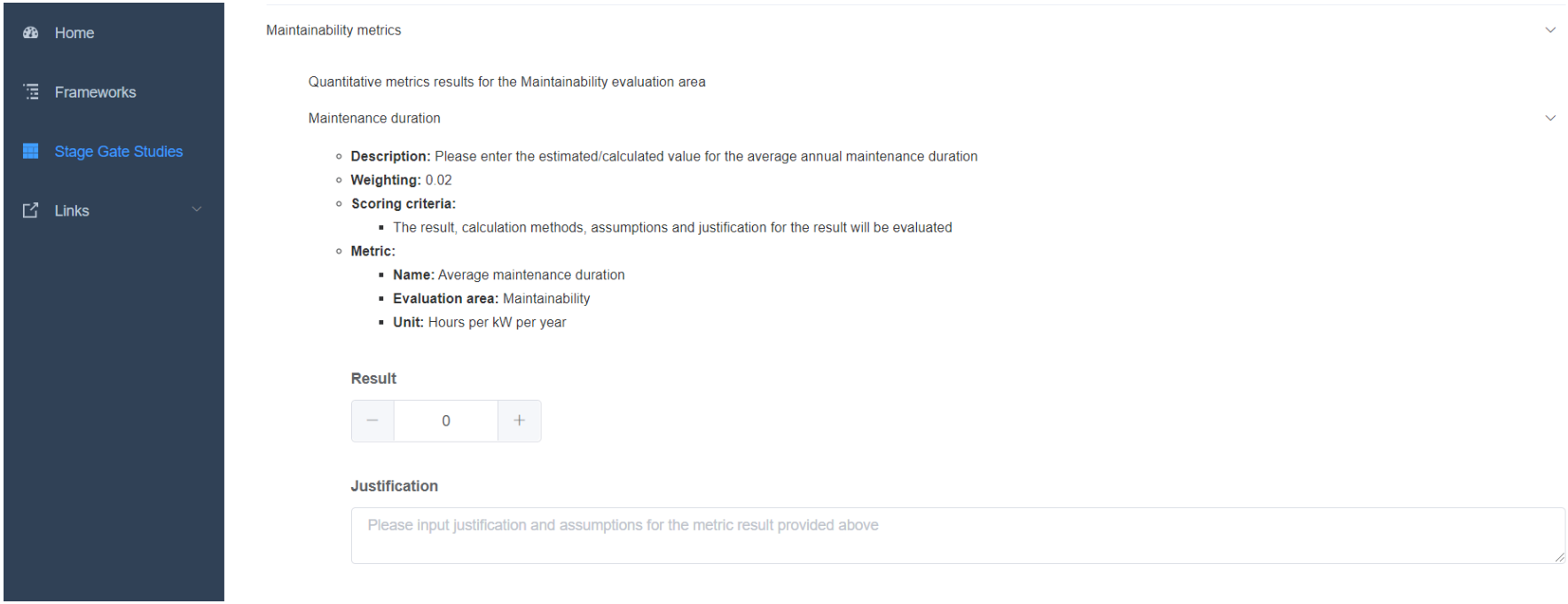
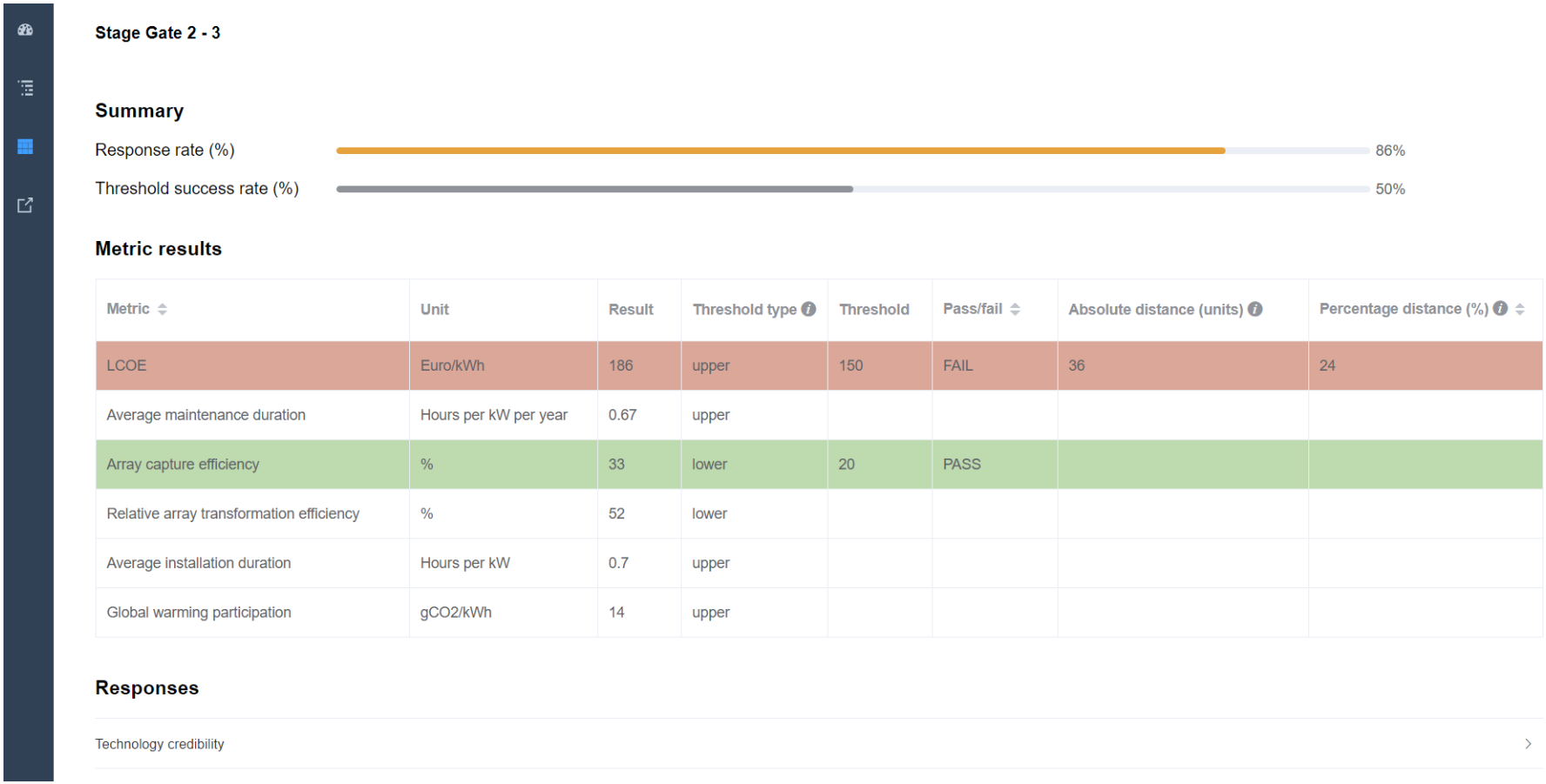


FIGURE 5-12: APPLICANT MODE INPUT PAGE - QUANTITATIVE QUESTION



Stage Gate 2 - 3

Summary

Response rate (%) 86%

Threshold success rate (%) 50%

Metric results

Metric	Unit	Result	Threshold type	Threshold	Pass/fail	Absolute distance (units)	Percentage distance (%)
LCOE	Euro/kWh	186	upper	150	FAIL	36	24
Average maintenance duration	Hours per kW per year	0.67	upper				
Array capture efficiency	%	33	lower	20	PASS		
Relative array transformation efficiency	%	52	lower				
Average installation duration	Hours per kW	0.7	upper				
Global warming participation	gCO2/kWh	14	upper				

Responses

Technology credibility

FIGURE 5-13: APPLICANT MODE RESULTS PAGE

5.4 ASSESSOR MODE

5.4.1 INPUTS

The input page for Assessor Mode presents the responses from Applicant Mode to the user alongside input boxes for the assessor scores and comment for each question. An example is given in Figure 5-14. The assessor comment is a text input box and the assessor score must be selected from a dropdown menu.

5.4.2 RESULTS

The Assessor Mode results page shows the average and weighted average scores for three different categories; the overall score, the scores for each question category and the scores for each evaluation area. Examples of the graphical summary of the assessor scores for the three categories are shown in Figure 5-15, Figure 5-16 and Figure 5-17. The assessor scores and comments are also presented to the user on the results page, but these are not shown in the screenshots.

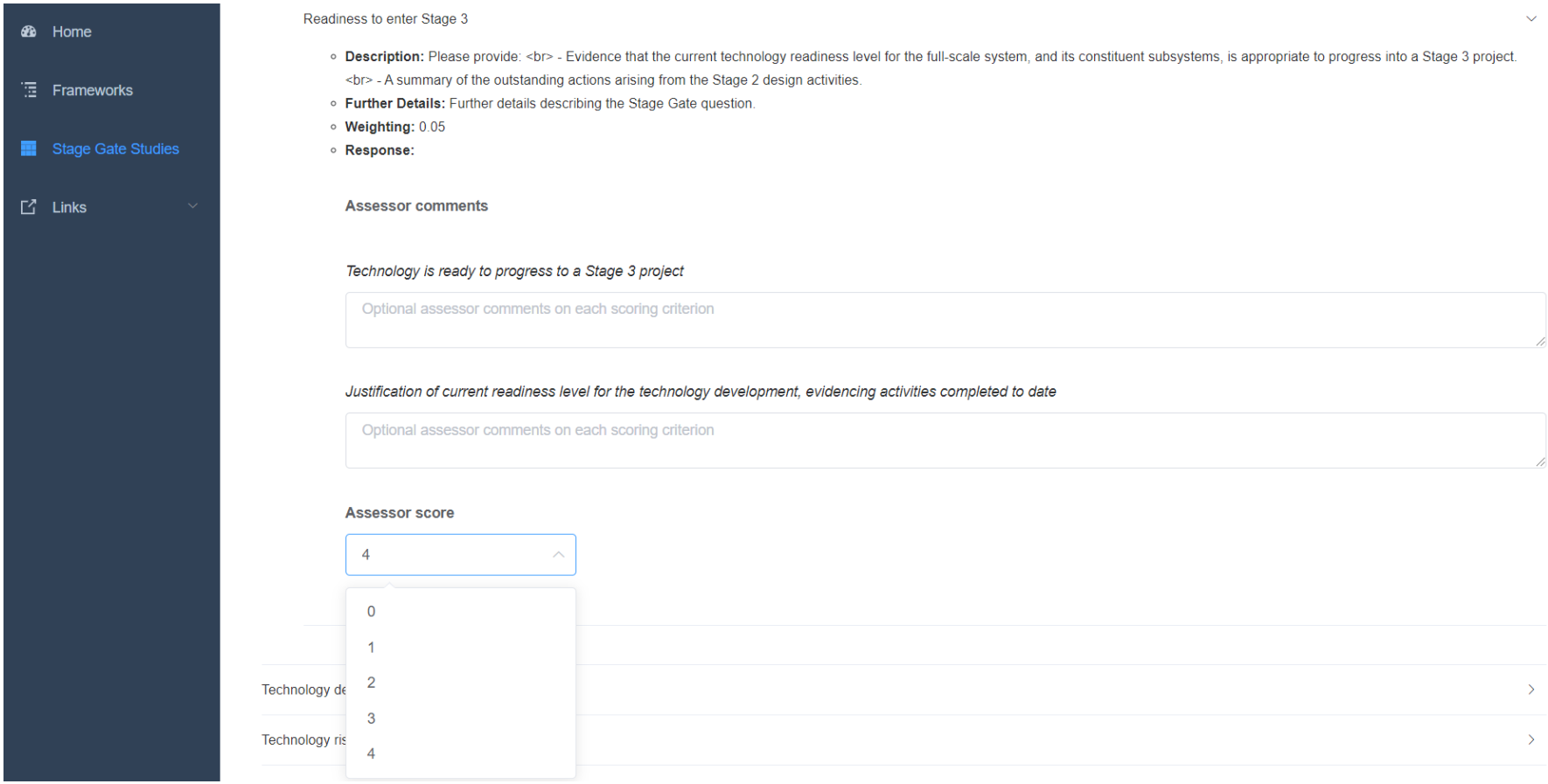


FIGURE 5-14: ASSESSOR MODE INPUT PAGE

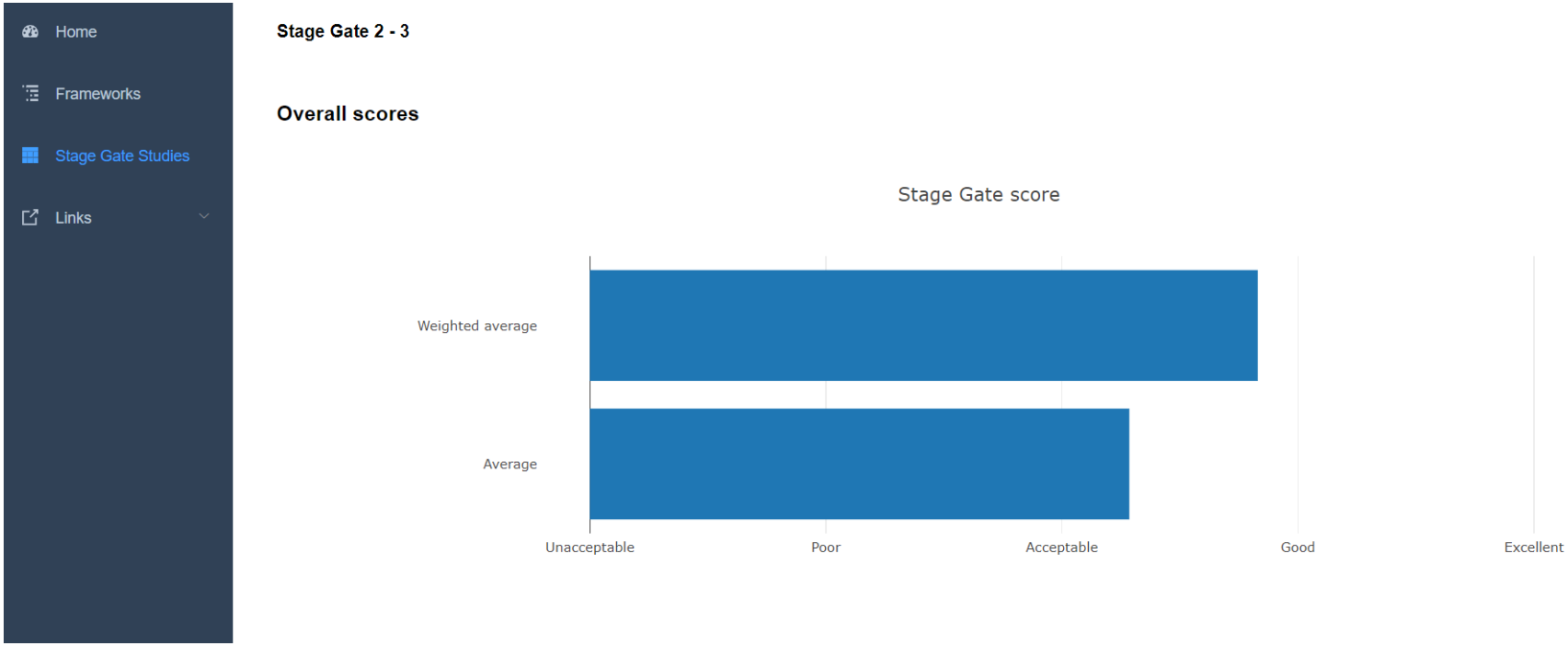


FIGURE 5-15: ASSESSOR MODE SUMMARY RESULTS

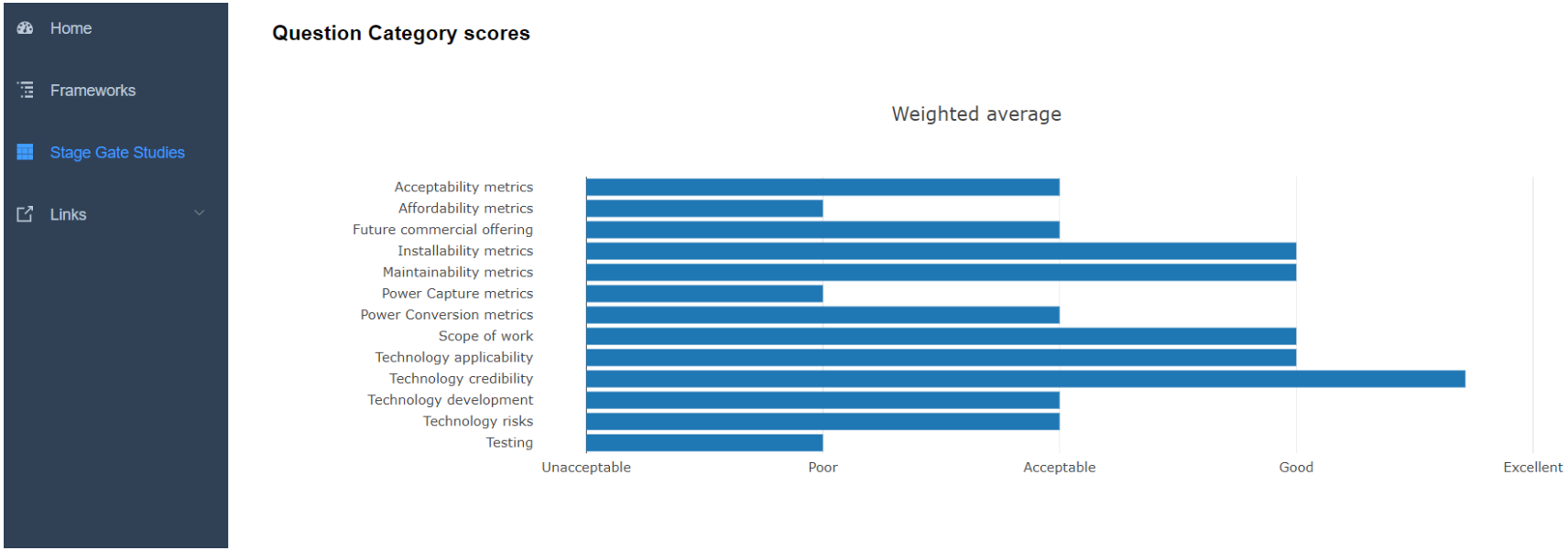


FIGURE 5-16: ASSESSOR MODE QUESTION CATEGORY RESULTS

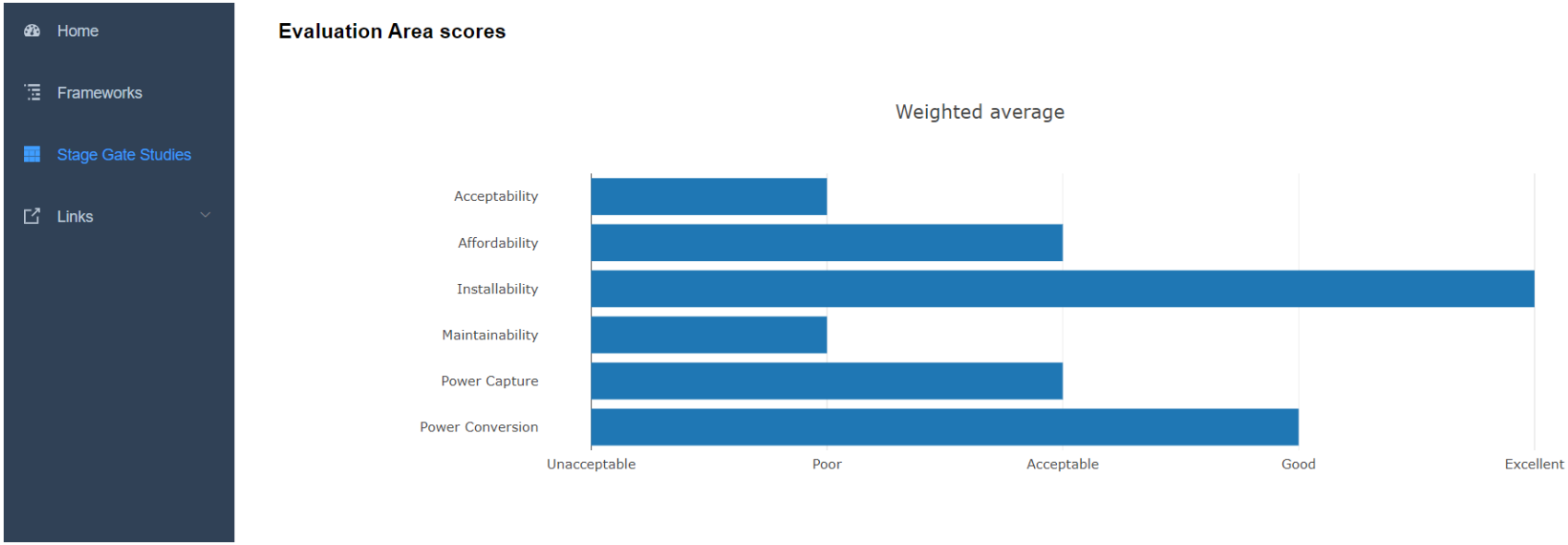


FIGURE 5-17: ASSESSOR MODE EVALUATION AREA RESULTS

6. FUTURE WORK

The present deliverable collects the main functional and technical aspects of the Stage Gate module (SG), implemented during the tasks T4.2 of the DTOceanPlus project. At the time of writing, the module can be run in a standalone mode. Some progress has been made toward the integration with other DTOceanPlus tools. For instance, a collaborative API was configured in which modules had to link to the schemas and routes they required from other modules. However, in order to fully integrate SG with the remaining modules of the DTOceanPlus suite of design tools, the following steps are required:

- The front-end (FE) unit tests and end-to-end (E2E) integration tests need to be extended to ensure 100% coverage for all the Stage Gate functionalities.
- Pact testing needs to be implemented. This is a tool for testing HTTP integrations using *contract testing*. This is a technique that tests an integration point by checking each application in isolation to ensure the messages it sends or receives conform to a shared understanding that is documented in a 'contract'[3]. Pact testing has already been set up for the Stage Gate tool and one of its provider modules. Tests need to be written for each of the modules that will interact with SG.
- The actual integration of the modules must then take place and *integration tests* must be developed. Integration testing is the phase in software testing in which individual software modules are combined and tested as a group. This task extends the preceding tasks of Dredd validation (which has been completed) and the Pact testing mentioned above.

These activities will be developed within task T4.3 - Verification of the Stage Gate Tool (beta version). These subsequent tasks will extend the functionalities of the Stage Gate module from the current standalone version to the final one which will be fully integrated in the DTOceanPlus toolset.

[3] See the Pact documentation for more details; https://docs.pact.io/

7. REFERENCES

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ANNEX: DATA WITHIN THE STAGE GATE DESIGN TOOL FRAMEWORK

A. STAGE ACTIVITIES

STAGE 0

Name	Description	Activity Category	Evaluation Area
Device concept definition	Concept definition and identification of physical/ functional characteristics and fundamental operating principles of energy capture device, including: - low/ medium/ high energy resource suitability - deep/shallow water - surface piercing/ floating/ bottom mounted - likely commercial-scale geometric size of the technology - mode of energy capture and degrees of freedom for energy capture - suitability for implementation of control systems to maximise performance - potential benefits of control systems - degree of reliance on control systems to achieve functionality	Concept creation and description	Energy Capture
Materials identification	Identification of key materials and structure types through concept description	Concept creation and description	Manufacturability
Sizing estimates for structure	Identification of rough commercial-scale size of key structural components and comparison to the existing industry capability	Concept creation and description	Manufacturability

Impact of control systems on installability	Evaluation of the potential for control system actions to be implemented and consideration of: - potential benefits to Installability - level of reliance on control to achieve installation	Concept creation and description	Installability
Hydrodynamic performance estimates	Basic estimates of hydrodynamic energy capture based on fundamental relationships between physical parameters (such as swept area or diameter) and power production of similar technologies	Hydrodynamic performance assessment	Energy Capture
Basic hydrodynamic calculations	Simple capture length ratio (wave) or power coefficient (tidal) calculations based on comparable technologies	Hydrodynamic performance assessment	Energy Capture
PTO concept definition	Concept definition and identification of physical/ functional characteristics and fundamental operating principles of PTO, including: - suitability for implementation of control systems to maximise performance - potential benefits of control systems - degree of reliance on control systems to achieve functionality	Power take off (PTO) considerations	Energy Transformation
Additional energy transformation details	Energy transformation behaviour and efficiency expectations based on (or derived from) existing, more mature technologies	Power take off (PTO) considerations	Energy Transformation
Potential for control systems (reliability)	Evaluation of the potential for control system actions to be implemented and consideration of: - potential benefits to Reliability - level of reliance on control to maintain Reliability	Control systems	Reliability

Potential for control systems (maintainability)	Evaluation of the potential for control system actions to be implemented and consideration of: - potential benefits to Maintainability - level of reliance on control to achieve Maintainability	Control systems	Maintainability
Basic CAPEX estimate	Basic estimates of CAPEX based on fundamental relationships between physical and economic parameters and cost of similar technologies (e.g. device, PTO or other subsystem)	Preliminary economic assessment	Affordability
Additional CAPEX detail	Use of typical project and technology level cost breakdowns from wider sector experience to extrapolate subsystem cost estimates to complete device CAPEX	Preliminary economic assessment	Affordability
Acceptability assessment	Basic evaluation of the general device characteristics in the context of how they correspond to general acceptability concerns and social benefits (e.g. visibility, submergence, marine life interactions, use of hazardous fluids/materials, etc.)	Environmental and social acceptance assessment	Acceptability
Evaluation of comparable technologies (installation)	Evaluation of the Installability of comparable technologies and applications. This evaluation should be based on the conceptual understanding of the technology and identification of physical and functional characteristics that impact Installability, including: - near/ far from shore - low/ med/ high energy - deep/ shallow water - surface piercing/ floating/ bottom mounted - likely commercial-scale size, transportability and vessel requirements	Comparable technology evaluation	Installability

	- potential complexity of connection and commissioning - identifiable Health, Safety and Environment (HSE) risks		
Evaluation of comparable technologies (reliability)	Evaluation of the reliability of comparable technologies and applications. This evaluation should be based on the conceptual understanding of the technology and identification of physical and functional characteristics that impact reliability or the requirement for a specific level of reliability, including: - near/ far from shore - deep/ shallow water - surface piercing/ floating/ bottom mounted - suitability for implementation of protective control and monitoring systems - proposed structural material considered, with respect to scale and loading scenarios and suitability for expected environmental exposure - concept mode of operation, moving parts, potential exposure, perceived susceptibility to damage	Comparable technology evaluation	Reliability
Evaluation of comparable technologies (maintenance)	Evaluation of the Maintainability of comparable technologies and applications. This evaluation should be based on the conceptual understanding of the technology and identification of physical and functional characteristics that impact Maintainability, including: - near/ far from shore - low/ med/ high energy - deep/ shallow water - surface piercing/ floating/ bottom mounted - likely accessibility, transportability and suitability for maintenance operations on-site or in a protected location	Comparable technology evaluation	Maintainability

	(harbour) - identifiable Health, Safety and Environment (HSE) risks		
Evaluation of comparable technologies (survivability)	Evaluation of the Survivability of comparable technologies and applications. This evaluation should be based on the conceptual understanding of the technology and identification of physical and functional characteristics that impact Survivability, including: - surface piercing/ floating/ bottom mounted - suitability for implementation of protective control and monitoring systems, potential Survivability benefits and level of reliance on control - proposed structural material considered with respect to scale and extreme loading scenarios and suitability for expected environmental exposure - concept mode of operation and any fundamental characteristics that improve the ability to survive extreme conditions	Comparable technology evaluation	Survivability
Evaluation of comparable technologies (availability)	Evaluation of the availability of comparable technologies and applications. This evaluation should be based on the conceptual understanding of the technology and identification of physical and functional characteristics that impact availability.	Comparable technology evaluation	Availability
Novelty evaluation (installability)	Evaluation of the novelty of the technology with respect to the state of the art and experience of application and installation in the ocean energy environment	Novel technology evaluation	Installability

Novelty evaluation (reliability)	Evaluation of the novelty of the technology with respect to the state of the art and experience of its application in the ocean energy environment	Novel technology evaluation	Reliability
Novelty evaluation (maintainability)	Evaluation of the novelty of the technology with respect to the state of the art and experience of application and maintenance in the ocean energy environment	Novel technology evaluation	Maintainability
Novelty evaluation (survivability)	Evaluation of the novelty of the technology with respect to the state of the art and experience of its application in the ocean energy environment	Novel technology evaluation	Survivability
Novelty evaluation (availability)	Evaluation of the novelty of the technology, focussing on availability. Evaluation should consider the state of the art as well as experience of applying the technology in the ocean energy environment.	Novel technology evaluation	Availability
Target selection (installability)	Selection of high-level Installability targets appropriate to the technology	Target selection	Installability
Target selection (reliability)	Selection of high-level reliability targets, appropriate to the technology	Target selection	Reliability
Target selection (maintainability)	Selection of high-level Maintainability targets appropriate to the technology	Target selection	Maintainability
Target selection (survivability)	Selection of high-level Survivability targets appropriate to the technology	Target selection	Survivability

Target selection (availability)	Selection of high-level availability targets appropriate to the technology	Target selection	Availability
Target selection (affordability)	Selection of high-level Affordability targets appropriate to the technology	Target selection	Affordability
Device concept definition	Concept definition and identification of physical/ functional characteristics and fundamental operating principles of energy capture device, including: - low/ medium/ high energy resource suitability - deep/shallow water - surface piercing/ floating/ bottom mounted - likely commercial-scale geometric size of the technology - mode of energy capture and degrees of freedom for energy capture - suitability for implementation of control systems to maximise performance - potential benefits of control systems - degree of reliance on control systems to achieve functionality	Concept creation and description	Energy Capture
Materials identification	Identification of key materials and structure types through concept description	Concept creation and description	Manufacturability
Sizing estimates for structure	Identification of rough commercial-scale size of key structural components and comparison to the existing industry capability	Concept creation and description	Manufacturability
Impact of control systems on installability	Evaluation of the potential for control system actions to be implemented and consideration of:	Concept creation and description	Installability

	- potential benefits to Installability - level of reliance on control to achieve installation		
Hydrodynamic performance estimates	Basic estimates of hydrodynamic energy capture based on fundamental relationships between physical parameters (such as swept area or diameter) and power production of similar technologies	Hydrodynamic performance assessment	Energy Capture
Basic hydrodynamic calculations	Simple capture length ratio (wave) or power coefficient (tidal) calculations based on comparable technologies	Hydrodynamic performance assessment	Energy Capture
PTO concept definition	Concept definition and identification of physical/ functional characteristics and fundamental operating principles of PTO, including: - suitability for implementation of control systems to maximise performance - potential benefits of control systems - degree of reliance on control systems to achieve functionality	Power take off (PTO) considerations	Energy Transformation
Additional energy transformation details	Energy transformation behaviour and efficiency expectations based on (or derived from) existing, more mature technologies	Power take off (PTO) considerations	Energy Transformation
Potential for control systems (reliability)	Evaluation of the potential for control system actions to be implemented and consideration of: - potential benefits to Reliability - level of reliance on control to maintain Reliability	Control systems	Reliability
Potential for control systems (maintainability)	Evaluation of the potential for control system actions to be implemented and consideration of:	Control systems	Maintainability

	- potential benefits to Maintainability - level of reliance on control to achieve Maintainability		
Basic CAPEX estimate	Basic estimates of CAPEX based on fundamental relationships between physical and economic parameters and cost of similar technologies (e.g. device, PTO or other subsystem)	Preliminary economic assessment	Affordability
Additional CAPEX detail	Use of typical project and technology level cost breakdowns from wider sector experience to extrapolate subsystem cost estimates to complete device CAPEX	Preliminary economic assessment	Affordability
Acceptability assessment	Basic evaluation of the general device characteristics in the context of how they correspond to general acceptability concerns and social benefits (e.g. visibility, submergence, marine life interactions, use of hazardous fluids/materials, etc.)	Environmental and social acceptance assessment	Acceptability
Evaluation of comparable technologies (installation)	Evaluation of the Installability of comparable technologies and applications. This evaluation should be based on the conceptual understanding of the technology and identification of physical and functional characteristics that impact Installability, including: - near/ far from shore - low/ med/ high energy - deep/ shallow water - surface piercing/ floating/ bottom mounted - likely commercial-scale size, transportability and vessel requirements - potential complexity of connection and commissioning - identifiable Health, Safety and Environment (HSE) risks	Comparable technology evaluation	Installability

Evaluation of comparable technologies (reliability)	Evaluation of the reliability of comparable technologies and applications. This evaluation should be based on the conceptual understanding of the technology and identification of physical and functional characteristics that impact reliability or the requirement for a specific level of reliability, including: - near/ far from shore - deep/ shallow water - surface piercing/ floating/ bottom mounted - suitability for implementation of protective control and monitoring systems - proposed structural material considered, with respect to scale and loading scenarios and suitability for expected environmental exposure - concept mode of operation, moving parts, potential exposure, perceived susceptibility to damage	Comparable technology evaluation	Reliability
Evaluation of comparable technologies (maintenance)	Evaluation of the Maintainability of comparable technologies and applications. This evaluation should be based on the conceptual understanding of the technology and identification of physical and functional characteristics that impact Maintainability, including: - near/ far from shore - low/ med/ high energy - deep/ shallow water - surface piercing/ floating/ bottom mounted - likely accessibility, transportability and suitability for maintenance operations on-site or in a protected location (harbour) - identifiable Health, Safety and Environment (HSE) risks	Comparable technology evaluation	Maintainability

Evaluation of comparable technologies (survivability)	Evaluation of the Survivability of comparable technologies and applications. This evaluation should be based on the conceptual understanding of the technology and identification of physical and functional characteristics that impact Survivability, including: - surface piercing/ floating/ bottom mounted - suitability for implementation of protective control and monitoring systems, potential Survivability benefits and level of reliance on control - proposed structural material considered with respect to scale and extreme loading scenarios and suitability for expected environmental exposure - concept mode of operation and any fundamental characteristics that improve the ability to survive extreme conditions	Comparable technology evaluation	Survivability
Evaluation of comparable technologies (availability)	Evaluation of the availability of comparable technologies and applications. This evaluation should be based on the conceptual understanding of the technology and identification of physical and functional characteristics that impact availability.	Comparable technology evaluation	Availability
Novelty evaluation (installability)	Evaluation of the novelty of the technology with respect to the state of the art and experience of application and installation in the ocean energy environment	Novel technology evaluation	Installability
Novelty evaluation (reliability)	Evaluation of the novelty of the technology with respect to the state of the art and experience of its application in the ocean energy environment	Novel technology evaluation	Reliability

Novelty evaluation (maintainability)	Evaluation of the novelty of the technology with respect to the state of the art and experience of application and maintenance in the ocean energy environment	Novel technology evaluation	Maintainability
Novelty evaluation (survivability)	Evaluation of the novelty of the technology with respect to the state of the art and experience of its application in the ocean energy environment	Novel technology evaluation	Survivability
Novelty evaluation (availability)	Evaluation of the novelty of the technology, focussing on availability. Evaluation should consider the state of the art as well as experience of applying the technology in the ocean energy environment.	Novel technology evaluation	Availability
Target selection (installability)	Selection of high-level Installability targets appropriate to the technology	Target selection	Installability
Target selection (reliability)	Selection of high-level reliability targets, appropriate to the technology	Target selection	Reliability
Target selection (maintainability)	Selection of high-level Maintainability targets appropriate to the technology	Target selection	Maintainability

STAGE 1

Name	Description	Activity Category	Evaluation Area
Concept characterisation (installability)	Evaluation of Installability characteristics of the technology - near/ far from shore - low/ med/ high energy - deep/ shallow water - surface piercing/ floating/ bottom mounted - likely commercial-scale size, transportability and vessel requirements - potential complexity of connection and commissioning - identifiable Health, Safety and Environment HSE risks	Concept characterisation	Installability
Concept characterisation (maintainability)	Evaluation of the Maintainability characteristics of the technology, including: - near/ far from shore - low/ med/ high energy - deep/shallow water - surface piercing/floating/bottom mounted - likely accessibility, transportability and suitability for maintenance operations on-site or in a protected location (harbour) - potential for control system actions to be implemented and consideration of potential benefits to Maintainability - level of reliance on control to perform maintenance	Concept characterisation	Maintainability
Concept characterisation (survivability)	Critical evaluation of physical and functional characteristics of the concept that impact Survivability, including: - modes of operation and any fundamental characteristics that improve the ability to survive extreme conditions	Concept characterisation	Survivability

	- suitability for implementation of protective control and monitoring systems		
Tank testing of energy capture technology	Tank testing of energy capture technology at approximately 1:50 - 1:20 scale with damping or power take-off method implemented to simulate behaviour of a real PTO, covering: - a range of sea-states or currents which provide scaled representation of the target commercial operating conditions to characterise the functional performance - where appropriate, variation of controllable parameters, such as damping or energy capture device geometry and evaluation of the impact on energy capture performance	Tank testing	Energy Capture
Evaluation of tank testing	Evaluation of physical and functional behaviours observed in tank testing conditions which can inform the characterisation of the device energy capture functionality and suitability for the expected range of operating conditions	Tank testing	Energy Capture
Demonstration of manufacturing process (tank tests)	Demonstration of manufacturing process through production of small-scale prototype for tank testing	Tank testing	Manufacturability
Rig testing of subsystems	Proof-of-concept rig testing main components or subsystems at appropriate scale to represent the functional behaviour of the PTO technology, covering: - a representative range of PTO input conditions - representation of inertia and other energy capture device-related phenomena - where appropriate, variation of controllable parameters, such as damping, to demonstrate a range of load factors	Rig testing	Energy Transformation

Demonstration of manufacturing process (rig tests)	Demonstration of manufacturing process through production of small-scale prototype for rig testing	Rig testing	Manufacturability
Numerical model (hydrodynamic performance)	Development of a numerical model, to estimate commercial-scale hydrodynamic performance	Numerical modelling	Energy Capture
Validate numerical model	Numerical model validation against tank test data	Numerical modelling	Energy Capture
Numerical model (extreme loads)	Development of a numerical model to estimate extreme commercial-scale loads	Numerical modelling	Survivability
Numerical model (commercial-scale loads)	Development of a numerical model or structural calculations to estimate commercial-scale loads	Numerical modelling	Reliability
Numerical model (energy transformation)	Development of a numerical model to estimate commercial-scale energy transformation performance and validation against rig test data	Numerical modelling	Energy Transformation
High-level installation plan	Development of a high-level installation plan based on the characteristics and scale of the technology and evidence of functional behaviours from tank testing which influence the Installability characteristics of the technology. This plan may take the form of a simple storyboard and must consider the HSE implications of the process.	Installation plan	Installability
Simple subsystem breakdown	Development of a simple concept subsystem breakdown and identification of the key B.O.M components	Simple BOM and CAPEX calculations	Manufacturability

Outline manufacturing process	Outline of manufacturing process for commercial-scale versions of key B.O.M components	Simple BOM and CAPEX calculations	Manufacturability
Manufacturing feasibility assessment	Assessment of the feasibility of manufacturing processes and key materials for the full or commercial-scale of the technology	Simple BOM and CAPEX calculations	Manufacturability
CAPEX evaluation of BOM	High-level CAPEX evaluation of key BOM components at commercial-scale	Simple BOM and CAPEX calculations	Affordability
Expand cost evaluation	Use of typical system and project cost breakdowns from wider sector experience to complete concept subsystem cost evaluation	Simple BOM and CAPEX calculations	Affordability
Structural component strength assessment	Identification of structural strength of provisionally selected structural materials	Structural material assessment	Reliability, Survivability
Structural component safety factors	High-level evaluation of safety factors of key structural components	Structural material assessment	Reliability, Survivability
Design limit states (reliability)	Identification of likely design limit states for reliability parameters	Design limit identification	Reliability
Design limit states (survivability)	Identification of likely design limit states for survivability parameters	Design limit identification	Survivability
Develop high-level O&M process	Development of a high-level O&M process including likely planned maintenance activities in response to: - the identification of key failure modes based on experience from wider application of similar technology and assessment of which parts of the system can be maintained	High level FMEA and O&M plan	Maintainability

	- evidence of any functional behaviours from tank testing which influence the Maintainability characteristics of the technology - HSE implications		
Identify failure modes	Use experience from wider application of similar technology to identify key failure modes and to estimate failure rates. High-level evaluation of identified failure modes and rates against the practical needs of a commercial deployment.	High level FMEA and O&M plan	Reliability
Integrate FMEA and O&M plan	Integration of high-level FMEA and O&M plans to evaluate availability, guided by knowledge from comparable technologies and applications	High level FMEA and O&M plan	Availability
Calculate LCOE	Integration of high-level CAPEX and OPEX evaluations with energy yield calculated by numerical energy capture and conversion models to calculate LCOE in a proposed energy resource or site	Affordability assessment	Affordability
General acceptability evaluation	Evaluation of the physical and functional characteristics of technology and potential deployment locations of the technology for general acceptability concerns and social benefits	Acceptability concerns and social benefits	Acceptability
Concept characterisation (installability)	Evaluation of Installability characteristics of the technology - near/ far from shore - low/ med/ high energy - deep/ shallow water - surface piercing/ floating/ bottom mounted - likely commercial-scale size, transportability and vessel requirements	Concept characterisation	Installability

	- potential complexity of connection and commissioning - identifiable Health, Safety and Environment HSE risks		
Concept characterisation (maintainability)	Evaluation of the Maintainability characteristics of the technology, including: - near/ far from shore - low/ med/ high energy - deep/shallow water - surface piercing/floating/bottom mounted - likely accessibility, transportability and suitability for maintenance operations on-site or in a protected location (harbour) - potential for control system actions to be implemented and consideration of potential benefits to Maintainability - level of reliance on control to perform maintenance	Concept characterisation	Maintainability
Concept characterisation (survivability)	Critical evaluation of physical and functional characteristics of the concept that impact Survivability, including: - modes of operation and any fundamental characteristics that improve the ability to survive extreme conditions - suitability for implementation of protective control and monitoring systems	Concept characterisation	Survivability
Tank testing of energy capture technology	Tank testing of energy capture technology at approximately 1:50 - 1:20 scale with damping or power take-off method implemented to simulate behaviour of a real PTO, covering: - a range of sea-states or currents which provide scaled representation of the target commercial operating conditions to characterise the functional performance - where appropriate, variation of controllable parameters,	Tank testing	Energy Capture

	such as damping or energy capture device geometry and evaluation of the impact on energy capture performance		
Evaluation of tank testing	Evaluation of physical and functional behaviours observed in tank testing conditions which can inform the characterisation of the device energy capture functionality and suitability for the expected range of operating conditions	Tank testing	Energy Capture
Demonstration of manufacturing process (tank tests)	Demonstration of manufacturing process through production of small-scale prototype for tank testing	Tank testing	Manufacturability
Rig testing of subsystems	Proof-of-concept rig testing main components or subsystems at appropriate scale to represent the functional behaviour of the PTO technology, covering: - a representative range of PTO input conditions - representation of inertia and other energy capture device-related phenomena - where appropriate, variation of controllable parameters, such as damping, to demonstrate a range of load factors	Rig testing	Energy Transformation
Demonstration of manufacturing process (rig tests)	Demonstration of manufacturing process through production of small-scale prototype for rig testing	Rig testing	Manufacturability
Numerical model (hydrodynamic performance)	Development of a numerical model, to estimate commercial-scale hydrodynamic performance	Numerical modelling	Energy Capture
Validate numerical model	Numerical model validation against tank test data	Numerical modelling	Energy Capture
Numerical model (extreme loads)	Development of a numerical model to estimate extreme commercial-scale loads	Numerical modelling	Survivability

Numerical model (commercial-scale loads)	Development of a numerical model or structural calculations to estimate commercial-scale loads	Numerical modelling	Reliability
Numerical model (energy transformation)	Development of a numerical model to estimate commercial-scale energy transformation performance and validation against rig test data	Numerical modelling	Energy Transformation
High-level installation plan	Development of a high-level installation plan based on the characteristics and scale of the technology and evidence of functional behaviours from tank testing which influence the Installability characteristics of the technology. This plan may take the form of a simple storyboard and must consider the HSE implications of the process.	Installation plan	Installability
Simple subsystem breakdown	Development of a simple concept subsystem breakdown and identification of the key B.O.M components	Simple BOM and CAPEX calculations	Manufacturability
Outline manufacturing process	Outline of manufacturing process for commercial-scale versions of key B.O.M components	Simple BOM and CAPEX calculations	Manufacturability
Manufacturing feasibility assessment	Assessment of the feasibility of manufacturing processes and key materials for the full or commercial-scale of the technology	Simple BOM and CAPEX calculations	Manufacturability
CAPEX evaluation of BOM	High-level CAPEX evaluation of key BOM components at commercial-scale	Simple BOM and CAPEX calculations	Affordability
Expand cost evaluation	Use of typical system and project cost breakdowns from wider sector experience to complete concept subsystem cost evaluation	Simple BOM and CAPEX calculations	Affordability

Structural component strength assessment	Identification of structural strength of provisionally selected structural materials	Structural material assessment	Reliability, Survivability
Structural component safety factors	High-level evaluation of safety factors of key structural components	Structural material assessment	Reliability, Survivability
Design limit states (reliability)	Identification of likely design limit states for reliability parameters	Design limit identification	Reliability
Design limit states (survivability)	Identification of likely design limit states for survivability parameters	Design limit identification	Survivability
Develop high-level O&M process	Development of a high-level O&M process including likely planned maintenance activities in response to: - the identification of key failure modes based on experience from wider application of similar technology and assessment of which parts of the system can be maintained - evidence of any functional behaviours from tank testing which influence the Maintainability characteristics of the technology - HSE implications	High level FMEA and O&M plan	Maintainability
Identify failure modes	Use experience from wider application of similar technology to identify key failure modes and to estimate failure rates. High-level evaluation of identified failure modes and rates against the practical needs of a commercial deployment.	High level FMEA and O&M plan	Reliability
Integrate FMEA and O&M plan	Integration of high-level FMEA and O&M plans to evaluate availability, guided by knowledge from comparable technologies and applications	High level FMEA and O&M plan	Availability

Calculate LCOE	Integration of high-level CAPEX and OPEX evaluations with energy yield calculated by numerical energy capture and conversion models to calculate LCOE in a proposed energy resource or site	Affordability assessment	Affordability
General acceptability evaluation	Evaluation of the physical and functional characteristics of technology and potential deployment locations of the technology for general acceptability concerns and social benefits	Acceptability concerns and social benefits	Acceptability

STAGE 2

Name	Description	Activity Category	Evaluation Area
Small-scale manufacturing process	Detailed development of manufacturing process for optimised small-scale (Stage 2) model/prototype	Manufacturing processes	Manufacturability
FEED for larger-scale technology	Front-end engineering design (FEED) of larger-scale (Stage 3) technology	Manufacturing processes	Manufacturability
Manufacture small-scale prototype	Manufacture of small-scale (Stage 2) model/prototype and development of strategy to improve future manufacturing processes	Manufacturing processes	Manufacturability
Large-scale manufacturing process	Definition of manufacturing processes and evaluation of feasibility for key B.O.M components of larger-scale (Stage 3) and commercial-scale (Stage 4) technology	Manufacturing processes	Manufacturability
Manufacturing feasibility assessment	Identification and engagement of capable fabrication partner in feasibility evaluation	Manufacturing processes	Manufacturability
Manufacturing cost and duration assessment	Assessment of manufacturing costs and duration and identification of process development requirements	Manufacturing processes	Manufacturability
Tank testing of energy capture technology	Tank testing of energy capture technology at approximately 1:30 - 1:20 scale with damping or power take-off method implemented to simulate behaviour of a real PTO, covering: - a range of sea-states or currents which provide scaled representation of the target commercial operating conditions to characterise the functional performance - where appropriate, variation of controllable parameters, such as damping or energy capture geometry and evaluation of the impact on energy capture performance	Tank testing	Energy Capture

Rig testing (PTO)	Rig testing of complete, optimised PTO subsystem at appropriate scale to represent the functional behaviour of the PTO technology , ideally covering : - full range of PTO input conditions, including extremes and representation of inertia and other energy capture device-related phenomena - complete characterisation of PTO functional performance including, where appropriate, variation of controllable parameters, such as damping, to demonstrate the full range of load factors	Rig testing	Energy Transformation
Rig testing (reliability)	Rig testing of key components at appropriate scale to inform life (or cycles) capability and failure rate experience	Rig testing	Reliability
Rig testing (survivability)	Rig testing of key components at appropriate scale and size to evaluate their suitability for the intended loading extremes	Rig testing	Survivability
Perform tank testing for survivability	Tank testing of small-scale device (approximately 1:100 - 1:25), with scale/size driven by reasonably achievable tank wave heights, at a range of extreme sea-states or currents, and other operating conditions identified as representing Survivability challenges to the specific technology	Survival tank testing	Survivability
Evaluate survival strategies	Demonstration and evaluation of the effectiveness and Reliability of survival strategies, including failsafe modes and algorithms to control variable parameters, such as damping or energy capture geometry, or other active Survivability modes	Survival tank testing	Survivability
Evaluate behaviour in extreme conditions	Evaluation of physical and functional behaviours in extreme simulated tank conditions which may result in catastrophic failures	Survival tank testing	Survivability
Measure structural forces	Measurement of structural forces in key components where prototype size permits	Survival tank testing	Survivability

Integrate device and PTO	Engagement between PTO and prime mover developers to simulate and evaluate the behaviour and performance of - the energy capture technology with integrated PTO and - the PTO subsystem in an ocean energy converter	Device and PTO integration	Energy Capture, Energy Transformation
Numerical model for hydrodynamic performance	Development of numerical model to estimate commercial-scale hydrodynamic performance	Numerical modelling	Energy Capture
Validation of hydrodynamic numerical model	Validation of the numerical model using tank test data	Numerical modelling	Energy Capture
Numerical model for full-scale loads	Development of numerical model to estimate commercial-scale loads, validated to the extent possible using rig testing	Numerical modelling	Reliability
Numerical model for extreme loads	Development of increased complexity structural numerical model to estimate commercial-scale loads	Numerical modelling	Survivability
Numerical model for energy transformation	Development of a numerical model to estimate commercial-scale energy transformation performance	Numerical modelling	Energy Transformation
Validation of energy transformation numerical model	Validation of the numerical model using rig test data	Numerical modelling	Energy Transformation
Assess likely full-scale load factors	Quantitative assessment of likely commercial-scale load factors in representative conditions from tank test, rig test and validated numerical modelling	Critical assessment of tests and numerical models	Reliability
Assess commercial scale safety factors	Increased confidence-level, quantitative assessment of likely commercial-scale safety factors in representative extreme conditions from rig test and numerical modelling validated to the extent possible with the limited ability to apply instrumentation to small-size models	Critical assessment of tests and numerical models	Survivability

Characteristics optimisation (installability)	Optimisation of fundamental Installability characteristics and development of technical solutions to maximise Installability, considering - near/ far from shore - low/ med/ high energy - deep/ shallow water - surface piercing/ floating/ bottom mounted - likely accessibility, transportability and suitability for maintenance operations on-site or in a protected location (harbour)	Characteristics optimisation	Installability
Characteristics optimisation (maintainability)	Optimisation of the design solutions in response to the fundamental Maintainability characteristics of the technology, including: - near/ far from shore - low/ med/ high energy - deep/ shallow water - surface piercing/ floating/ bottom mounted - likely accessibility, transportability and suitability for maintenance operations on-site or in a protected location (harbour)	Characteristics optimisation	Maintainability
Develop installation plan	Development of a detailed installation plan including: - types of vessels (installation vessel, support vessel, ROV), with gross indication of vessel and equipment costs - consideration of marine operations feasibility and delays with respect to Maintainability characteristics, vessel/operator capability and expected environmental conditions - detailed storyboard defining the installation process, including on-shore transportation, launch method, transit to deployment site , connection (mooring and electrical) and	Detailed installation plan	Installability

	commissioning - evaluation of HSE implications of the installation plan		
Develop FMEA	Development of an FMEA based on FEED (Front End Engineering Design) activity for Stage 3 open-water test device, tank-test & modelling data, and Reliability experience from wider application of similar technology	FMEA and O&M model	Reliability
Develop O&M model	Development of an O&M model including: - failure modes from FMEA - weather and metocean condition simulation - vessel and other infrastructure availability, capability and cost data - duration of maintenance actions, and estimates of replacement component cost and availability - operational limitations and restrictions - evaluation of HSE implications of the O&M plan	FMEA and O&M model	Maintainability
Integrate FMEA and O&M model	Integration of FMEA and O&M model to evaluate availability in a target commercial deployment location	FMEA and O&M model	Availability
Highlight failure modes using O&M model	Use of O&M model to guide design optimisation by highlighting key failure modes	FMEA and O&M model	Maintainability
Develop LCOE model	Development of a Levelised Cost of Energy (LCOE) model integrating: - a BOM for the commercial-scale technology and detailed costing to evaluate CAPEX of the system or subsystem under development - typical system and project cost breakdowns from wider sector experience to provide cost evaluation of other systems or subsystems - O&M model and FMEA to evaluate availability and OPEX - Energy yield evaluated using numerical energy capture and conversion models	LCOE model	Affordability

Evaluate LCOE	Application of suitable learning rates and economies-of-scale to evaluate LCOE for: - the first-of-a-kind commercial-scale prototype (Stage 4) - a "mature sector" technology in a 10MW array at 1GW global installed capacity	LCOE model	Affordability
Evaluate environmental impact of manufacturing	Evaluation of greenhouse gases e.g. CO_2 production in potential manufacturing methods	Acceptability assessment	Acceptability
Assess potential deployment sites	Identification of the presence of stressors and receptors at potential deployment sites	Acceptability assessment	Acceptability

STAGE 3

Name	Description	Activity Category	Evaluation Area
Large-scale manufacturing process	Detailed development of manufacturing process for optimised Stage 3 scale technology	Manufacturing processes	Manufacturability
Manufacture large-scale prototype	Manufacture of sea-going (Stage 3) prototype and development of strategy to improve future manufacturing processes	Manufacturing processes	Manufacturability
Manufacturing process demonstration	In the case of supporting technologies such as structural components or materials, manufacture of a component at sufficient scale to demonstrate the manufacturing process and de-risk application at commercial scale	Manufacturing processes	Manufacturability
FEED of commercial-scale technology	Front-end engineering design (FEED) of commercial-scale technology	Manufacturing processes	Manufacturability
Commercial-scale manufacturing process	Definition of manufacturing processes and confirmed feasibility for all B.O.M components of the commercial-scale technology, with engagement of key supply chain, manufacturing and fabrication partners	Manufacturing processes	Manufacturability
Manufacturing cost and duration assessment	Assessment of manufacturing costs & duration and identification of process development requirements	Manufacturing processes	Manufacturability

Develop complete installation plan	Development of a complete installation plan in preparation for open-water deployment, including: - port requirements definition and port selection - launch method definition - specification of vessels (installation vessel, support vessel, ROV) with detailed evaluation of vessel and equipment costs - detailed assessment of marine operations feasibility and delays with respect to technology characteristics, specific site conditions, vessel/operator capability and expected environmental conditions - specification of transport vessel routes for site - specification of station-keeping and electrical connection solution - definition of HSE actions to be implemented in the installation plan	Installation plan	Installability
Independent review of installation plan	Engage competent persons to complete independent review of installation and operations plan e.g. quayside lifting plans, the marine operations plans	Installation plan	Installability
Develop complete O&M model and plan	Development of a complete O&M model and an O&M plan in preparation for open-water deployment, including: - information from commercial-scale FMEA - information from technology fabrication and operational experience - planned and unplanned maintenance cost and repair times - weather and metocean condition simulation - vessel and other infrastructure availability, capability and cost data - duration of maintenance actions and replacement component cost and availability - operational limitations and restrictions	FMEA, O&M model and plan	Maintainability

	- resulting waiting times, predicted O&M activity and system availability		
HSE action definition	Definition of HSE actions to be implemented in the O&M plan	FMEA, O&M model and plan	Maintainability
Use O&M model to highlight failure modes	Use of O&M model to guide O&M plan optimisation by highlighting key failure modes	FMEA, O&M model and plan	Maintainability
Develop commercial-scale FMEA	Development of FMEA for the technology's commercial-scale BOM, informed by testing and analysis experience	FMEA, O&M model and plan	Reliability, Survivability
Integrate FMEA and O&M model	Refined integration of FMEA and O&M model to evaluate availability in a target commercial deployment location	FMEA, O&M model and plan	Availability
Open-water testing of device	Open-water testing (uncontrolled environment) of energy capture device at sufficient scale and size to represent commercial-scale performance (1:6 - 1:2 depending on site selection and subsystem size) with an integrated, fully functional PTO and application of appropriate algorithms to vary controllable parameters, such as damping or energy capture geometry	Open-water testing	Reliability, Installability, Survivability, Availability, Energy Capture
Open-water testing requirements (energy capture)	Open-water test campaign of sufficient duration to fully evaluate the device energy capture performance through sustained periods of continuous generation in representative conditions: - for wave devices, this is expected to be at least 6 months , depending on the season, to reasonably expect experience of the full range of target energy generation sea-states - for tidal stream, this should cover at least one full tidal cycle (lunar cycle)	Open-water testing	Energy Capture

Open-water testing requirements (reliability)	Open-water test campaign should be of sufficient duration to demonstrate Reliability through sustained periods of continuous operation in representative conditions (i.e. energised and in a generating state). This is expected to be at least 6 months, depending on the season, to reasonably expect significant recurrence of the operational sea-states and currents, especially any of particular concern to the key failure modes	Open-water testing	Reliability
Open-water testing requirements (BOM)	Open-water testing (uncontrolled environment) of energy capture device (or subsystems in an open-water test rig) at sufficient scale to represent commercial-scale (1:6 - 1:2) behaviour and performance with representative subsystems and Bill of Materials (BOM)	Open-water testing	Reliability
Practical demonstration of installation plan	Practical demonstration of the installation plan through installation (and any retrievals/re-installations) during an open-water test programme (up to 6 months) at sufficient scale and size to represent commercial-scale marine operations. This is likely to be 1:6 - 1:2 scale.	Open-water testing	Installability
Open-water testing requirements (control)	Open-water testing (uncontrolled environment) of energy capture device at sufficient scale to represent commercial-scale performance (1:6 - 1:2 depending on site selection and subsystem size) with an integrated, fully functional PTO and application of appropriate algorithms to vary controllable parameters, such as damping or energy capture geometry	Open-water testing	Energy Capture, Survivability

Open-water testing requirements (survivability)	Open-water test campaign should be of sufficient duration to experience representative extreme/Survivability conditions: - for wave this could be a single deployment at a test location which experiences scaled extreme conditions, or a further dedicated deployment in a more exposed test environment - for tidal stream, this should cover at least one full tidal cycle (lunar cycle) including exposure to representative wind, wave and turbulence conditions (as appropriate to the technology)	Open-water testing	Survivability
Demonstration of survival strategies	Demonstration and evaluation of survival strategies (including algorithms to control variable parameters, such as damping, energy capture geometry, or other active Survivability modes) through open-water test campaign of a device at sufficient scale and size to represent commercial-scale behaviour (1:6 - 1:2)	Open-water testing	Survivability
Validate availability	Validation of availability evaluation using open-water deployment, operation, maintenance and retrieval experience	Open-water testing	Availability
Practical demonstration of O&M plan	Practical demonstration of the O&M plan through operation and maintenance activity (or demonstration of the ability to carry out activity) during an open-water test programme (up to 6 months) at sufficient scale to represent commercial-scale marine operations. This is likely to be 1:6 - 1:2 scale.	Open-water testing	Maintainability
Rig testing of complete PTO system	Rig testing of complete PTO subsystem at sufficient scale to represent commercial-scale performance, in readiness for integration with device, covering: - full range of PTO input conditions, including extremes and representation of inertia and other energy capture device-related phenomena - demonstration of operational characteristics of PTO functional performance including, where appropriate,	Rig testing	Energy Transformation

	variation of controllable parameters, such as damping, to demonstrate the full range of load factors		
Accelerated life testing of subsystem	Accelerated life testing at suitable rig scale and size to inform key subsystem, or device or subsystem component, life (or cycles) capability and failure rates. This work should support the developing Reliability management plan and be coherent with the developing FMEA and O&M plan	Rig testing	Reliability
Rig testing for extreme structural loads	Continued rig testing at a scale sufficient for representation of extreme conditions with structural load measurement	Rig testing	Survivability
Tank testing of energy capture technology	Tank testing of optimised energy capture technology at approximately 1:30 - 1:20 scale with damping or power take-off method implemented to simulate behaviour of a real PTO, covering: - a range of sea-states or currents which provide scaled representation of the target commercial operating conditions to characterise the functional performance - where appropriate, variation of controllable parameters by optimised algorithms, such as damping or energy capture geometry and evaluation of the impact on energy capture performance	Tank testing	Energy Capture
Tank testing for extreme structural loads	Continued tank testing at a scale sufficient for representation of extreme conditions with structural load measurement	Tank testing	Survivability
Numerical model (commercial-scale loads)	Further improvement in the fidelity of numerical models to calculate commercial-scale loads, validated using open-water test data	Numerical modelling	Reliability
Numerical model (extreme loads)	Further development of increased complexity numerical model to calculate commercial-scale loads and safety factors in extreme conditions	Numerical modelling	Survivability

Numerical model (integrated PTO)	Further development and validation of a detailed numerical hydrodynamic performance model to cover full operational envelope, with integrated fully-operational scale PTO represented	Numerical modelling	Energy Capture
Numerical model (energy transformation)	Development of a complete numerical model to calculate commercial-scale energy transformation performance, both in isolation (rig-conditions) and integrated in an energy capture device	Numerical modelling	Energy Transformation
Validate numerical model with rig data	Validation of the numerical model using rig test data	Numerical modelling	Energy Transformation
Load reduction analysis	Application and evaluation of algorithms to allow variation of controllable parameters, such as damping or energy capture geometry, which could provide Reliability benefits through load reduction or mitigation	Reliability analyses	Reliability
Record system failures and structural loads	Application of structural load measurement and monitoring of system failures	Reliability analyses	Reliability
Optimise LCOE model	With further knowledge gained from wider stage 3 activities, development of a Levelised Cost of Energy (LCOE) model integrating: - a BOM for the commercial-scale technology and detailed costing to evaluate CAPEX of the system or subsystem under development and other systems or subsystems that have been developed in detail as part of the Stage-3-scale prototype - typical system and project cost breakdowns from wider sector experience to provide cost evaluation of other systems or subsystems - O&M model and FMEA to evaluate availability and OPEX - Energy yield evaluated using numerical energy capture and conversion models	LCOE model	Affordability

Evaluate LCOE	With further knowledge gained from wider stage 3 activities, application of suitable learning rates and economies-of-scale to evaluate LCOE for: - the first-of-a-kind commercial-scale prototype (Stage 4) - a "mature sector" technology in a 10MW array at 1GW global installed capacity	LCOE model	Affordability
Evaluate CO_2 emissions of vessels	Evaluation of CO_2 emissions from O&M and installation vessels (based on Installation & O&M plans)	CO_2 emissions	Acceptability
Evaluate CO_2 emissions of manufacture	Evaluation of CO_2 emissions from manufacture based on B.O.M and experience of procurement and assembly of stage 3-scale prototype	CO_2 emissions	Acceptability
Estimate social value of project	Estimate of social value of commercial-scale project based on jobs and supply created etc	Environmental and social acceptance assessment	Acceptability
Identify stressors and receptors	Identification of the presence of stressors and receptors at potential or selected deployment sites	Environmental and social acceptance assessment	Acceptability

STAGE 4

Name	Description	Activity Category	Evaluation Area
Commercial-scale manufacturing process	Detailed development of manufacturing process for optimised commercial-scale Energy Capture device and subsystems	Manufacturing processes	Manufacturability
Manufacture commercial-scale device	Manufacture of sea-going commercial-scale technology and development of strategy to improve future manufacturing processes	Manufacturing processes	Manufacturability
Verify manufacturing costs and durations	Detailed identification and verification of manufacturing costs & durations	Manufacturing processes	Manufacturability
Integrate commercial device and PTO	Integration of the commercial PTO subsystem with a commercial-scale energy capture device	Integrate PTO and device	Energy Transformation
Update O&M model	Update and any required extension of the O&M model and O&M plan in preparation for open-water deployment including: - failure modes from FMEA based on commercial-scale technology design and BOM - information from technology fabrication and operational experience - information from commercial-scale FMEA - information from technology fabrication and operational experience - planned and unplanned maintenance cost and repair time - weather and metocean condition simulation - vessel and other infrastructure availability, capability and cost data - duration of maintenance actions and replacement component cost and availability - operational limitations and restrictions	FMEA, O&M model and plan	Maintainability

	- resulting waiting times, predicted O&M activity and system availability		
Develop commercial-scale installation plan	Development of a complete, commercial-scale installation plan in preparation for open-water deployment, including: - ports requirements definition and port selection - launch method definition - specification of vessels (installation vessel, support vessel, ROV) with detailed evaluation of vessel and equipment costs - detailed assessment of marine operations feasibility and delays with respect to commercial technology design, specific site conditions, vessel/operator capability and expected environmental condition - specification of transport vessel routes for site - specification of station-keeping and electrical connection solution - definition of HSE actions to be implemented in the installation plan	Installation plan	Installability
Use O&M model to highlight failure modes	Use of O&M model to guide O&M plan optimisation by highlighting key failure modes	FMEA, O&M model and plan	Maintainability
Independent review of installation plan	Engage external experts to complete independent review of installation/ operations plan	Installation plan	Installability
Develop commercial-scale FMEA	Development of complete FMEA including catastrophic failures	FMEA, O&M model and plan	Survivability
Integrate FMEA and O&M model	Integration of FMEA and O&M model (for a single device) and extrapolation to a future array to evaluate availability in a target commercial deployment	FMEA, O&M model and plan	Availability
HSE action definition	Definition of HSE actions to be implemented in the O&M plan	FMEA, O&M model and plan	Maintainability

Open-water testing	Open-water testing (uncontrolled environment) of a single energy capture device at commercial scale, in a commercially representative site, with integrated commercial-scale, fully functional PTO and application of appropriate algorithms to vary controllable parameters, such as damping or energy capture geometry	Open-water testing	Reliability, Installability, Survivability, Maintainability, Availability, Energy Capture
Open-water testing requirements (energy capture)	Open-water test campaign should be of sufficient duration, with no significant periods of operational interruption, to evaluate the device energy capture performance to a high level of confidence. For wave and tidal devices, this is expected to be at least 12 months in order to experience the full range of expected operating conditions	Open-water testing	Energy Capture
Practical demonstration of installation plan	Practical demonstration of the installation plan through installation (and any retrievals/re-installations) during an open-water test programme of at least 12-month duration, gaining evidence to validate the claimed window of acceptable installation metocean conditions, installation time and cost.	Open-water testing	Installability
Open-water testing requirements (reliability)	Open-water test campaign should be of sufficient duration to demonstrate Reliability through a period of deployment in representative conditions with no significant periods of operational interruption, to generate experience to support FMEA validation. This is expected to be up to 12 months to experience of the full range of target operational sea-states and currents	Open-water testing	Reliability
Open-water testing requirements (BOM)	Open-water testing (uncontrolled environment) of a single commercial-scale device, representing the commercial BOM (all sub-systems)	Open-water testing	Reliability

Open-water testing requirements (control)	Open-water testing (uncontrolled environment) of a single energy capture device at commercial-scale with integrated commercial-scale, fully functional PTO and application of appropriate algorithms to vary controllable parameters, such as damping or energy capture geometry and implement survival modes as appropriate	Open-water testing	Energy Capture, Survivability
Open-water testing requirements (survivability)	Open-water test campaign should be of sufficient duration to ensure exposure to extreme/Survivability conditions. For wave and tidal devices, this is expected to be at least 12 months	Open-water testing	Survivability
Demonstration of survival strategies	Demonstration and evaluation of survival strategies on commercial-scale device, including algorithms to control variable parameters, such as damping or energy capture geometry, or other active Survivability modes	Open-water testing	Survivability
Validate availability	Validation of availability evaluation using open-water deployment, operation, maintenance and retrieval experience	Open-water testing	Availability
Practical demonstration of O&M plan	Practical demonstration of the O&M plan through operation and maintenance activity (or demonstration of the ability to carry out activity) during a 12-month open-water test programme, gaining evidence to validate the claimed window of acceptable O&M metocean conditions, and operational times and costs.	Open-water testing	Maintainability
Open-water testing requirements (energy transformation)	Open-water test campaign of sufficient duration, with no significant periods of operational interruption, to evaluate the energy transformation performance of the PTO to a high level of confidence. For wave and tidal PTOs, this is expected to be at least 12 months in order to experience the full range of expected operating conditions (both energy capture of device, and PTO input operating conditions and load factors) and to demonstrate sustained performance over an extended duration	Open-water testing	Energy Transformation

Rig testing of commercial-scale PTO	Rig testing of commercial-scale PTO subsystem, covering: - full range of PTO input conditions, including extremes and representation of inertia and other energy capture device-related phenomena - complete characterisation of PTO functional performance including, where appropriate, variation of controllable parameters, such as damping, to demonstrate the full range of load factors	Rig testing	Energy Transformation
Accelerated life testing of subsystem	On-going accelerated life testing at appropriate rig scale and size to build confidence in key subsystem, or device or subsystem component, life (or cycles) capability and failure rate	Rig testing	Reliability
Rig testing for extreme structural loads	Continued rig testing at a scale and size sufficient for representation of extreme conditions with structural load measurement	Rig testing	Survivability
Integrated numerical model	Development of a complete numerical model that covers the full operational envelope, with integrated commercial-scale PTO that can represent energy transformation performance across a range of input conditions and load factors	Numerical modelling	Energy Capture, Energy Transformation
Validate integrated numerical model	Validation of the numerical model using rig and open-water test data	Numerical modelling	Energy Capture, Energy Transformation
Continuous monitoring (reliability)	Structural load measurement and monitoring of system failures, combined with further development and validation of numerical structural model to build detail and confidence in FMEA including component, subsystem and device failure modes, failure rates and MTTF	Measurement and monitoring	Reliability
Continuous monitoring (survivability)	Structural load measurement and monitoring of system failures, combined with further development and validation of numerical structural model to build detail and confidence of catastrophic failure mode understanding	Measurement and monitoring	Survivability

Complete BOM	Completion of a BOM for the commercial-scale technology including all systems and subsystems	LCOE model	Affordability
Finalise detailed LCOE model	Finalisation of a Levelised Cost of Energy (LCOE) model integrating: - Detailed costing of the realised commercial scale BOM to evaluate CAPEX - Refined availability, energy capture and conversion modelling to evaluate availability, OPEX and energy yield - Evaluation of array infrastructure, balance of plant, learning rates, operational and finance costs from wider sector experience	LCOE model	Affordability
Apply final LCOE model	Application of suitable learning rates and economies-of-scale to evaluate LCOE for a "mature sector" technology in a 10MW array at 1GW global installed capacity	LCOE model	Affordability
Create baseline EIA	Creation of a baseline study for an Environmental Impact Assessment (EIA) for potential/ deployment sites	Environmental impact assessment	Acceptability
Evaluate CO_2 emissions of vessels	Detailed evaluation of CO_2 emissions from O&M and installation vessels (based on Installation & O&M plans)	CO_2 emissions	Acceptability
Evaluate CO_2 emissions of manufacture	Evaluation of CO_2 emissions from manufacture based on B.O.M and experience of procurement and assembly of commercial-scale prototype	CO_2 emissions	Acceptability
Calculate social value of project	Calculation of social value of commercial-scale project based on jobs and supply created etc	Environmental and social acceptance assessment	Acceptability
Identify stressors and receptors	Identification of the presence of stressors and receptors at potential or selected deployment sites	Environmental and social acceptance assessment	Acceptability

STAGE 5

Name	Description	Activity Category	Evaluation Area
Optimise commercial-scale manufacturing process	Optimisation of manufacturing process for optimised commercial-scale technology including array infrastructure	Manufacturing processes	Manufacturability
Manufacture sea-going devices	Manufacture of at least 3 (or an additional 2 after Stage 2) sea-going commercial-scale Energy Capture devices, subsystems, and associated array infrastructure	Manufacturing processes	Manufacturability
Finalise commercial-scale BOM	Finalisation of B.O.M for optimised commercial-scale technology including array infrastructure	Manufacturing processes	Manufacturability
Verify manufacturing costs and durations	Detailed identification and verification of manufacturing costs & durations	Manufacturing processes	Manufacturability
Optimise commercial-scale installation plan	Optimisation of a complete, commercial array-scale installation plan in preparation for open-water deployment including: - ports requirements definition, selection and launch method - specification of vessels (installation vessel, support vessel, ROV) with detailed evaluation of vessel and equipment costs - detailed assessment of marine operations feasibility and delays with respect to commercial technology design, specific site conditions, vessel/operator capability and expected environmental conditions - specification of transport vessel routes for site - specification of station-keeping and electrical connection solution, including array inter-connections and other array-related infrastructure - definition of HSE actions to be implemented in the installation plan	Installation plan	Installability
Independent review of installation plan	Independent review of installation / operations plan	Installation plan	Installability

Integrate device and PTO for multiple devices	Integration of the commercial PTO subsystem to an array of at least 3 commercial scale devices in intended commercial deployment conditions	Integrate PTO and device	Energy Transformation
Select array layout	Selection of array layout based on hydrodynamic modelling and array interaction analysis	Array configuration	Energy Capture
Update O&M model	Update and any required extension of the O&M model and O&M plan in preparation for open-water deployment including: - extension to represent array deployment and infrastructure - failure modes from FMEA based on commercial-scale technology design and BOM - information from technology fabrication and operational experience - information from commercial-scale FMEA - information from technology fabrication and operational experience - planned and unplanned maintenance cost and repair time - weather and metocean condition simulation - vessel and other infrastructure availability, capability and cost data - duration of maintenance actions and replacement component cost and availability - operational limitations and restrictions - resulting waiting times, predicted O&M activity and system availability	FMEA, O&M model and plan	Maintainability
Use O&M model to highlight failure modes	Use of O&M model to guide O&M plan optimisation by highlighting key failure modes	FMEA, O&M model and plan	Maintainability
Complete integration of FMEA and O&M model	Complete integration of FMEA and O&M model to evaluate availability of an array of commercial devices in a target commercial deployment location	FMEA, O&M model and plan	Availability

Use O&M Model to inform EIA	Final, established O&M plan and model used to calculate environmental impact of O&M activities	FMEA, O&M model and plan	Acceptability
HSE action definition (maintainability)	Definition of HSE actions to be implemented in the O&M plan	FMEA, O&M model and plan	Maintainability
Open-water testing of array	Open-water testing (uncontrolled environment) of an array of at least 3 commercial-scale devices, in a commercially representative site, with integrated commercial scale, fully functional PTO and application of appropriate algorithms to vary controllable parameters, such as damping or energy capture geometry	Open-water testing	Energy Capture
Open-water testing requirements (energy capture)	Open-water test campaign should be of sufficient duration, with no significant periods of operational interruption, to evaluate the array energy capture performance to a high level of high-confidence. For wave and tidal devices, this is expected to be at least 5 years in order to experience the full range of expected operating conditions and build statistical significance of performance characteristics	Open-water testing	Energy Capture
Practical demonstration of installation plan	Practical demonstration of the installation plan through installation (and any retrievals/re-installations) during an open-water test programme of at least 5 years duration with an array of 3 or more devices, gaining evidence to validate the claimed window of acceptable installation metocean conditions, installation time and cost.	Open-water testing	Installability
Open-water testing requirements (reliability)	Open-water test campaign should be of sufficient duration (up to 5 years) to demonstrate and evaluate Reliability across the full range of operational sea-states and currents. Periods of operational interruption should be minimised, and primarily focussed on general maintenance, to support FMEA validation.	Open-water testing	Reliability

Open-water testing requirements (BOM)	Open-water testing in representative conditions (uncontrolled environment) of a small array of at least 3 commercial-scale devices, which each utilise the commercial-scale BOM (including all sub-systems)	Open-water testing	Reliability
Open-water testing requirements (control)	Open-water testing (uncontrolled environment) of an array of at least 3 energy capture devices at commercial scale with integrated commercial scale, fully functional PTO and application of appropriate algorithms to vary controllable parameters, such as damping or energy capture geometry and implement survival modes as appropriate	Open-water testing	Energy Capture, Survivability
Open-water testing requirements (survivability)	Open-water test campaign should be of sufficient duration to ensure exposure to extreme/Survivability conditions. For wave and tidal arrays, this is expected to be at least 5 years to build confidence of long-term Survivability	Open-water testing	Survivability
Demonstration of survival strategies	Demonstration and evaluation of survival strategies on commercial-scale device, including algorithms to control variable parameters, such as damping or energy capture geometry, or other active Survivability modes	Open-water testing	Survivability
Validate availability	Validation of availability evaluation using open-water deployment, operation, maintenance and retrieval experience	Open-water testing	Availability
Open-water testing requirements (energy transformation)	Open-water test campaign of sufficient duration, with no significant periods of operational interruption, to evaluate the PTOs energy transformation performance to a high level of high-confidence. For wave and tidal PTOs, this is expected to be at least 5 years in order to experience the full range of expected operating conditions (both energy capture device and PTO input operating conditions and load factors) and build statistical significance of performance characteristics and demonstrate sustained performance over a long duration	Open-water testing	Energy Transformation

Practical demonstration of O&M plan	Practical demonstration of the O&M plan through operation and maintenance activity (or demonstration of the ability to carry out activity) during a 5-year open-water test programme, gaining evidence to validate the claimed window of acceptable O&M metocean conditions, and operational times and costs.	Open-water testing	Maintainability
Accelerated life testing of subsystem	On-going accelerated life testing at appropriate rig scale and size to build confidence in key subsystem, or device or subsystem component, life (or cycles) capability and failure rate	Rig testing	Reliability
Integrated numerical model for array	Ongoing validation of a detailed numerical model, to cover full operational envelope, with integrated fully-operational scale PTO represented and inclusion of any array-related hydrodynamic interaction effects to reflect the installed configuration and future array deployments	Numerical modelling	Energy Capture
Validate integrated numerical model	Full validation of detailed numerical model of the PTO, integrated with the device hydrodynamic numerical model	Numerical modelling	Energy Transformation
Continuous monitoring (reliability)	Structural load measurement and monitoring of system failures, combined with ongoing development and validation of numerical structural model to build detail and confidence of FMEA including component, subsystem, device and array failure modes, failure rates and MTTF	Measurement, monitoring and optimisation	Reliability
Finalise reliability management approach	Complete definition of commercial Reliability management approach, including monitoring, prognostics/diagnostics and any ongoing accelerated life test and management approaches to predict and mitigate future operational interruptions	Measurement, monitoring and optimisation	Reliability
Continuous monitoring (survivability)	Structural load measurement and monitoring of system failures, combined with ongoing development and validation of numerical structural model to build detail and confidence	Measurement, monitoring and optimisation	Survivability

	of catastrophic failure mode understanding and representation in FMEA		
Optimise controllable parameters	Validation and ongoing optimisation of any algorithms to vary controllable parameters, such as damping or energy capture geometry.	Measurement, monitoring and optimisation	Energy Capture
Finalise array BOM	Finalisation of BOM for optimised commercial-scale technology including all systems, subsystems and array infrastructure	LCOE model	Affordability
Finalise LCOE model	Finalisation of a Levelised Cost of Energy (LCOE) model integrating - Detailed costing of the realised commercial-scale array BOM to evaluate CAPEX - Refined availability, energy capture and conversion modelling to evaluate availability, OPEX and energy yield	LCOE model	Affordability
Apply final LCOE model	Application of suitable learning rates and economies-of-scale to evaluate LCOE for a "mature sector" technology in a 10MW array at 1GW global installed capacity	LCOE model	Affordability
Evaluate greenhouse gas emissions	Detailed evaluation of greenhouse gases like CO_2 production in manufacturing methods based on experience of procurement of parts and assembly of full/commercial-scale prototype	Greenhouse gas emissions	Acceptability
Refine baseline EIA	Refinement of a baseline study for an EIA for potential site	Environmental impact assessment	Acceptability
Life cycle analysis (LCA)	Analysis of commercial-scale device (LCA) based on operational experience of full-scale system	Environmental impact assessment	Acceptability
Calculate social value of project	Estimate of social value of full-scale project based on jobs created etc.	Environmental and social acceptance assessment	Acceptability
Identify stressors and receptors	Identification of the presence of stressors and receptors at potential deployment sites	Environmental and social acceptance assessment	Acceptability

B. QUALITATIVE QUESTIONS AND SCORING CRITERIA

STAGE GATE 0-1

Name	Description	Scoring criteria	Question Category
Scientific credibility	Please explain how: •the underlying physical and scientific principles of energy conversion have been identified, understood and described in a concise technology description, •the basic hydrodynamic philosophies, likely properties, operational characteristics and interaction of the concept with the wave/tidal resource have been thought through and can be explained, •subtleties and elegancies in the concept can be explained scientifically.	▫ Concept operation and performance is demonstrated to be in alignment with scientific and hydrodynamic principles. ▫ The principles of operation are insightful and are driven by a good understanding of the underlying physics.	Technology credibility
Technical credibility	Please provide the following evidence: • a qualitative description (maybe supplemented by basic analysis and/or simulations), detailing how the concept can be designed or controlled so as to perform efficiently in the design wave/tidal conditions, but can regulate power and can shed load in more extreme conditions • an identification of the factors which are likely to influence performance, response and loading (typically related to dimensions, dimensional rations and dynamic characteristics) and how they will be explored • evidence of understanding of how the primary concept might interface with other elements of the	▫ The concept addresses the need for efficient performance in the design wave/tidal conditions. ▫ The concept addresses the need to regulate power and shed load in more extreme conditions.	Technology credibility

	system • an outline of the approach to the early development of the concept, showing for instance exploration of many options using critical techniques such as design inversion and lateral thought. •a list of lab or tank test work carried out and/or simulation and modelling work which has been done to prove the viability of the concept		
Engineering credibility	Please provide: • an outline describing the main engineering challenges and options that flow from the technical concept, showing there is credibility in the potential solutions • evidence of a systems engineering approach leading to a particularly attractive solution • a qualitative assessment of the concept's physical and functional characteristics from a perspective of survivability, reliability, performance and cost, showing that the overall engineering profile is promising • evidence showing, through early qualitative consideration, the engineering credibility (perhaps with new materials and processes) of manufacture, installation and operation • a set of aspirational targets, justified using the above qualitative consideration, for the concepts future achievement in terms of survivability, reliability, energy capture, energy conversion, cost, manufacturability, installability	▫ The concept has the potential to survive in an extreme ocean environment ▫ The concept has the potential to be reliable ▫ The concept offers good prospects of being engineered using known or emerging techniques and materials. ▫ There is a credible narrative surrounding installation, operation and maintenance. ▫ Credible targets are provided for aspirational performance in key evaluation areas	Technology credibility

Innovation	Please provide: • evidence that a technology appraisal has been undertaken such as thorough desk based and/or patent reviews of existing technologies. • a credible narrative as to how the technology is different (and an improvement upon) status-quo solutions and these advantages can be clearly expressed in terms of; o the improved scientific, technical or engineering characteristics, o the improved LCOE (qualitative or quantitative) that the innovation may have through reliability, survivability, performance or affordability, o the differences from existing systems/approaches, whether incremental or radical, and how these differences address current deficiencies.	▫ The concept is innovative and novel. It has distinct advantages over existing devices and /or families of devices. ▫ For devices that are already known, there is a clear path of investigation that could lead to significant improvements in the primary conversion system (e.g. new approaches to load limiting, significant enhancements to performance through dimension modification or other characteristics)	Technology development
Disadvantages	Please describe the key risks associated with the concept, analysing the potential challenges and downsides associated, discussing their likelihood and potential impact (ideally in terms of survivability, reliability, performance and cost metrics) and providing a strategy to avoid or mitigate them.	▫ There is clarity over any disadvantages and there is a credible approach presented to avoiding or mitigating them.	Technology risks
Integration and systemisation	Please provide: • A summary of studies into the options that exist for integrating the concept with other system elements. • A list of the main options that exist for these elements, their relative attractions and the currently preferred system configuration. • A brief discussion of the technical performance and	▫ The concept demonstrates potential to be integrated with other system components. ▫ A credible narrative has been provided regarding PTO design, control as well as station keeping	Technology applicability

	readiness levels of these elements and of their commercial readiness.		
Diversity	Please provide evidence that: • Applicants have appreciation of the wave/tidal energy technology landscape, perhaps through market technology appraisal, drawing on multiple sources (e.g. patent analysis, public sector reports, databases etc.). • Applicants can categorise the innovation by device or concept family, • the technology is under represented, has a unique nature within the sector and/or is applied in a novel approach (e.g. floating/fixed etc.).	▫ The concept adds to the diversity within the sector by: • adding a significant new enhancement to an existing device, • adding a significant new device to an existing family or • adding a significant new family to the sector	Technology applicability
Absolute long-term levelised cost of energy potential	Please provide: • An outline of the factors affecting LCOE for your concept, in particular showing interaction with wider system elements and describing how the design development will trade off survivability, reliability, performance and cost. • A simple LCOE calculation, showing how immediate term innovation coupled with longer term cost reductions through volume, learning and standardisation, will achieve the LCOE cost targets taking due account of uncertainty	▫ There is a convincing narrative, specifically based around the performance, reliability, survivability and cost profile, which suggests the concept has the potential to meet the system LCOE targets.	Cost of energy potential
Relative LCOE potential	Please provide a narrative on how the concept's LCOE prospects compare to those within the same (or similar) concept family and to those for the wider	▫ There is a technically based narrative that demonstrates that the innovation has prospects to improve best-in-class LCOE.	Cost of energy potential

	sector, referencing figures where required as evidence.		
Absolute long-term potential	Please provide: • Estimates of alternative metrics such as kW/tonne, kW/m3 or energy payback period • Clear and credible modelling cost assumptions and uncertainty estimates	▫ There is a convincing narrative, specifically based around the performance, reliability, survivability and cost profile, which suggests the concept has the potential to meet the system LCOE targets ▫ There is a pathway for enabling technology (e.g. for materials), if required.	Future targets
Utility-scale relevance	Please describe: • The scaling attributes of the concept and the drivers and constraints on device size. • Limitations on the upscaling of individual devices. • How multiple devices would be deployed in farm/array formation. • What a circa 100 MW array might look like spatially. • How you see the technology being brought to market. • Any market studies for the concept you have undertaken.	▫ The concept is relevant to utility scale power generation (this does not per-se exclude 'niche' developer concepts if upscaling has a clear pathway).	Future commercial offering

STAGE GATE 1-2

Name	Description	Scoring criteria	Question Category
Engineering description of technology	Provide an engineering description of your novel device		Technology credibility
Degree of novelty and innovation (I)	Describe the technological innovation being implemented, how it will improve best-in-class.	▫ The novelty and innovation of the technology is based on sound scientific, technical and engineering principles and remains likely to improve best-in-class performance. ▫ Identification of any dependencies on wider technical breakthroughs, and the likelihood of this being successful.	Technology credibility
Technology readiness	Describe the current state of technology development and the anticipated trajectory of development required to permit large scale testing in the marine environment in the near to medium term (3-5 years). Provide evidence to support this.	▫ The trajectory of technology development is credible. ▫ The underpinning technologies to facilitate large scale testing this WEC/TEC design are identified. ▫ WEC/TEC design will be technically ready for testing at a large scale (<1:2) in the marine environment within the near to medium term (3-5 years).	Technology development
Technical risks	Describe the key technical risks with the technology identified during the Stage 1 activities, and how these risks will be managed.	▫ A technology risk register is provided, recording the challenges associated with the technology. The level of detail is appropriate for Stage 1 development. ▫ There is clarity on the technical risks associated with the device, and credible strategies are presented for avoiding or mitigating them in the future.	Technology risks

Degree of novelty and innovation (II)	Describe why the innovations could be considered a significant step change alternative to existing state of the art ocean energy technologies.	▫ Justification for a significant step change alternative to existing state of the art ocean energy technologies. ▫ Identification of the attractions and advances in availability, performance, affordability and survivability offered by this solution over current state-of-the-art alternatives.	Technology applicability
Business case and impact	Provide a summary business plan, indicating the target market, anticipated market size and outline the long-term commercialisation strategy for the technology.	▫ Credible description of the route to market for the technology ▫ The technology has strong market potential and a clear, long-term commercialisation prospect. ▫ Provide reasoned justification of the long-term socio-economic impact of the technology. (covering energy security, cost reductions, life-cycle environmental impact, developing industrial capacity, supporting jobs and industry)	Future commercial offering

STAGE GATE 2-3

Name	Description	Scoring criteria	Question Category
Scaled, sea-going prototype characteristics	Please describe the baseline for the current state of the technology, the fundamental technical and engineering principles, the requirements for integration of subsystems, and the proposed design geometry.	▫ A succinct description of the proposed technology, highlighting the layout, constituent systems/subsystems and key interfaces that will be included on the scaled sea-going prototype to be manufactured during the Stage 3 project.	Technology credibility
Readiness to enter Stage 3	Please provide: • Evidence that the current technology readiness level for the full-scale system, and its constituent subsystems, is appropriate to progress into a Stage 3 project. • A summary of the outstanding actions arising from the Stage 2 design activities.	▫ Technology is ready to progress to a Stage 3 project ▫ Justification of current readiness level for the technology development, evidencing activities completed to date	Technology credibility
Device characteristics and Stage 2 performance	Please provide a summary of the characteristics of the proposed full-scale system	▫ Device characteristics data, informed by Stage 2 design activities, are provided ▫ A critical assessment of the performance of the WEC technology is provided	Technology development
Technology risks	Please provide: • A comprehensive list of the technical risks and the associated mitigations which must be addressed to achieve commercial success. • Probability, Impact and Risk score for unmitigated and mitigated risks. • Risk identification/risk last reviewed dates.	▫ A comprehensive set of risks are presented identifying the main areas of concern with the proposed technology ▫ Appropriate and achievable mitigations are presented to reduce the identified risk scores ▫ Risk probability and impact scores are appropriate ▫ The technical risk register includes details of the risk owner, date last reviewed, and impact/probability/risk scores identified both pre- and post-mitigation	Technology risks

Technology selling points	Please describe: • the selling points and opportunities afforded by the proposed technology, and why it is considered attractive to potential investors. • other technologies within the sector, comparable both in technology type and stage of development.	▫ Opportunities and selling points of the proposed technology are credible ▫ Response demonstrates an understanding of the proposed technology's position relative to other developments within the sector ▫ The technology is a credibly pitched and offers an attractive investment opportunity.	Technology applicability
Commercialisation route	Please describe: • How the technology will become commercially competitive for utility scale energy generation in the long term. • The current trajectory for the technology, recognising both its inherent strengths and weaknesses. • Which intermediate development steps are necessary in order to become commercially competitive.	▫ Strength of commercial argument proposed by Applicant ▫ Credible, intermediate technology development steps are indicated and justified in the context of the plan for the long-term development of the technology and the challenges and limits which exist ▫ Dependence on external factors and/or developments are explored	Future commercial offering

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