# ELEMENT: VERIFICATION FRAMEWORK

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 815180.

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# GLOSSARY

| Abbreviation or Term | Definition |
|---|---|
| Design Team | The team responsible for the design and engineering development of the control system and tidal energy converter in which the control system will be implemented. Led by Nova Innovation, the Design Team also includes Wood, the University of Strathclyde, Nortek, France Energies Marines, ABB, ORE Catapult, Innosea and Chantier Bretagne-Sud. |
| FMECA | Failure Modes and Effects Criticality Analysis |
| LOP | List of Open Points |
| NCR | Non-Conformance Report |
| Validation | The confirmation by examination and the provision of objective evidence that the particular requirements for a specific intended use are fulfilled. |
| Verification | The process to check that a product, service, or system (or part thereof) meets a defined set of design specifications. |
| Verification Team | The team responsible for the verification of design specifications and validation of project requirements. Led by Wood, the Verification Team also includes Nova Innovation, DNV-GL, ORE Catapult, IDETA, University of Strathclyde, and Chantier Bretagne-Sud. |
| VFR | Verification Framework Report |

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# 1. INTRODUCTION

A Funding Grant was awarded from the European Union's Horizon 2020 research and innovation programme to develop and validate an innovative tidal turbine control system, using the tidal turbine itself as a sensor, to deliver a step change improvement in turbine performance. This will demonstrate Effective Lifetime Extension in the Marine Environment for Tidal Energy (ELEMENT), driving the EU tidal energy sector to commercial reality. This project is funded under the call LC-SC3-RES-11-2018: Developing solutions to reduce the cost and increase performance of renewable technologies.

This document is produced as an outline and overview of the verification process that is proposed, and is also to be submitted to satisfy public deliverable D3.1 of the ELEMENT project. This document should be read in conjunction with the following document:

- ELEMENT-EU-0005 – D6.1-Behavioural Model Specification

The above document provides a high-level specification for the ELEMENT behavioural model, and an outline of the testing and validation plan.

The Verification Framework Report (VFR) outlines the proposed processes and assessment activities that will enable the appropriate verification activities, validation of the design and underpinning calculations and coding activity, and also the on and offshore testing phases that will be carried out over the project duration. It defines the verification and validation objectives, and the scope of these activities at relevant stages of the project, and how it is envisaged that the project will be subject to appropriate verification and validation of results.

The VFR comprises of a number of sections relevant to each stage in the project verification – namely design verification, onshore verification, and offshore verification (tow testing, inshore testing, and offshore testing). The level of detail contained in this document is to be appropriate for the type of project being delivered and needs to be sufficiently detailed to manage the project verification process effectively.

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# 2. BACKGROUND

The ELEMENT project will develop and validate a radically innovative control system for a tidal turbine, using adaptive machine learning based on state-of-the-art tidal turbine operating knowledge and industry leading technology from the wind energy industry. This is expected to deliver a step change improvement in the performance of the tidal energy sector.

A project of this nature requires the involvement of organisations with a wide range of skills coming together and working closely in collaboration as a Consortium. The starting point for this project is a tidal turbine with a standard controller. This system is designed to withstand the maximum expected loads during operational life, including peak loads and fatigue. Fatigue and peak loads contribute to wear and tear on a device; this reduces device reliability, availability, efficiency and lifetime, and increases operational costs (OPEX).

Improved control of turbines to reduce damaging loads can significantly improve device reliability and extend the lifetime of components, leading to reduced OPEX. In addition, improved control and a better understanding of the resource and the turbine response can be used to optimise performance to significantly increase device yield and reduce environmental impact, for minimal additional CAPEX. The project will therefore focus on the development and validation of an innovative control system to address these issues in order to deliver improved performance.

To ensure that the developed technology meets with a defined set of functional specifications and design specifications (verification), and that examination of objective evidence to corroborate that particular requirements for a specific intended use are fulfilled (validation), a defined process should be outlined to provide an overview of 'what' and 'how' verification and validation activities would be carried out. It is this process that will be outlined within this report, which will outline the framework for verification and validation within the ELEMENT project.

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# 3. PROJECT AIM AND OBJECTIVES

## 3.1. Project Aim

The Consortium's aim is to reduce the Levelised Cost of Energy (LCOE) for tidal energy by 17%, driving the EU tidal energy sector to commercial reality, as presented in Figure 1. This will be achieved through the development and validation of a radically innovative tidal turbine control system, using the tidal turbine itself as a sensor. By enhancing an existing tidal turbine controller and combining it with state-of-the-art control technology developed for wind turbines, the ELEMENT project will use behavioural modelling and artificial intelligence to optimise performance and deliver an adaptive control system.

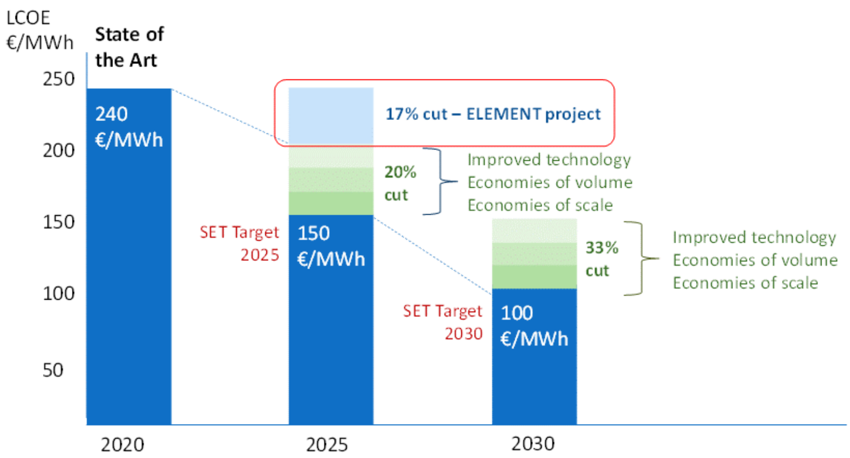


*Figure 1: Target LCOE Reduction*

The specific objectives of the ELEMENT project are detailed in Table 1 below, along with their associated outcome/expected impact.

*Table 1 ELEMENT project specific objectives*

| Objectives | Outcome / Expected impact |
|---|---|
| Optimise the control system of a tidal turbine, using behavioural modelling to reduce predicted loads | Reduce fatigue loads experienced by the device by 50% (estimated, baseline = loads experienced by operational Nova M100 turbines) |
| Use improved understanding of turbine behaviour to maximise energy yield | Increase energy extraction from the device by 8% (estimated, baseline = current yield of NOVA turbines) |
| Utilise results to optimise tidal turbine design for world-leading improved performance and reduced cost | Reduce Levelized Cost of Energy (LCOE) of tidal power by 17% (baseline = LCOE of NOVA turbines) |
| Develop and validate adaptable control technology with a wide range of applications | Validate the ELEMENT control system to TRL5 in multiple applications. |
| Minimise environmental impacts by integrating environmental monitoring into the control system | Reduce the estimated risk of collision with marine fauna by 50% (baseline = modelled collision risk for NOVA turbines) |
| Increased resistance to marine environment & extended lifetime of tidal turbines | Increase estimated lifetime of tidal devices and key components by 25% (estimated baseline = lifetime of existing NOVA turbines/components) |
| Maximise shared learning between EU projects | Shared knowledge with a minimum of five EU funded projects relating to offshore renewable energy |
| Improve the knowledge base regarding impacts of tidal energy on the environment and local communities | Deliver a socio-economic and environmental assessment of the potential impact of tidal energy on the local economy (Étel), France, and Europe |
| Increase public support for tidal energy projects | Deliver a targeted Communications Strategy focussing on the potential societal benefits of tidal energy |

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## 3.2. WP3 – Verification and Commercialisation

Work Package 3 of the Element project, Verification and Commercialisation, has four primary objectives:

1. Formalise the Verification Framework for the project that sets out how the system design and experimental results will be verified.
2. Verify the project outputs: that the system design and test results—onshore, tow testing, in-sea estuary and in-sea offshore deployment—meet the product specification and the project objectives across all major tidal deployment locations (river/estuary, floating and subsea).
3. Develop a Roadmap to Certification for the ELEMENT technology, setting out the steps required to go from prototype to a certified product, in light of emerging standards in the tidal energy sector.
4. Develop a Commercialisation Strategy for the ELEMENT technology, identifying the target markets (including potential applications outside tidal energy), target customers, competitor analysis, route to market, potential barriers, priorities for further research and IP considerations.

The means by which objectives 1 and 2 will be achieved shall be outlined within this report. Item 1 will be satisfied with the submission of this deliverable. Item 2 will be completed through the ongoing verification and validation throughout the ELEMENT project, at intervals that shall be defined within this VFR. Items 3 and 4 are part of the verification work package, but as they are not verification activities, they will not be discussed within the VFR. The Roadmap to Certification and the Commercialisation Strategy will form separate deliverables within the project and shall be independent of the verification activities discussed in this report.

## 3.3. Verification Process Objective

Verification is an important component of a robust quality management system[1]. Nova Innovation and the ELEMENT project partners recognise the need to implement a suitable verification programme in order to reduce the technology risk associated with the development of novel technology, and to progress the Technology Readiness Level (TRL) of the system. The objective of the ELEMENT project is to bring the system from its current development stage to implementation within a fully functional and operational tidal stream turbine.

By the completion of the ELEMENT project, it is expected that Nova Innovation and project partners will have delivered robust verification and validation of the control system, such that it can be implemented, with confidence, in future tidal turbines.

To perform the verification work, Wood will follow industry best practice for the development and qualification of new systems and technology. The main documents that can be considered as relevant references for the purposes of the verification activities within the ELEMENT project are:

- IEC TS 62600-4 ED1 - Marine energy - Wave, tidal and other water current converters - Part 4: Standard for establishing qualification of new technology;
- DNVGL-SE-0163 – Certification of tidal turbines and arrays;
- DNVGL-ST-0164 - Tidal turbines;
- DNVGL-SE-0160 – Technology qualification management and verification;
- DNV-GL-RP-A203 – Technology Qualification

[1] ISO 9001:2015 - Quality management systems: Requirements, Section 8.3.4 c)

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# 4. VERIFICATION FRAMEWORK

This framework utilises the experience and knowledge gained from previous projects, and builds upon the lessons learned to establish the ELEMENT verification framework and the principles that underpin the proposed verification and validation work within the ELEMENT project.

## 4.1. Methodology

### 4.1.1. Overview

The VFR sets out the means of verification that will be utilised within the ELEMENT project, and facilitates the preparation of verification activities, split into five distinct phases: design, onshore testing, tow testing, estuary testing, and offshore testing. It will cover the following items within each phase:

- An overview of the selected approach to conducting the verification and/or validation.
- Overview of appropriate means of verification/validation.
- Definition of appropriate measurement, recording, and documenting methods.
- Identification of the necessary tools (e.g., test rig, sensors, hardware, measurement and recording software), facilities (e.g., research laboratory, consented sea bed deployment location), and qualifications (e.g. certificates of compliance with regulations and standards, staff CVs for experienced personnel) that will be required in order to carry out testing that meets the requirements of the verification strategy.
- Examples of relevant outputs and supporting documentation that will serve as evidence.

Reference will be made to two specific teams within the context of this framework – the "Design Team" and the "Verification Team".

The detailed design of the ELEMENT control system will be carried out by the Design Team. This is the engineering team responsible for the development of input requirements (such as the Design Basis, Functional Requirements, and Detailed Design Specifications), the detailed design of the systems and sub-systems that aim to meet the input requirements and specifications, and the provision of supporting evidence to assist the verification process. The Design Team consists of team members from Nova Innovation (lead), and also includes Wood, the University of Strathclyde, Nortek, France Energies Marines, ABB, ORE Catapult, Innosea and Chantier Bretagne-Sud.

The verification and validation process will be overseen by the Verification Team, consisting of representatives from Wood and also includes Nova Innovation, DNV-GL, ORE Catapult, IDETA, University of Strathclyde, and Chantier Bretagne-Sud. Wood will have overall responsibility within the Verification Team and will lead the verification process. The Verification Team shall review all evidence associated with each verification stage to determine whether acceptance criteria have been met.

It is envisaged that the control system developed within the ELEMENT project will follow a V-Model approach to verification and validation. At each stage of the development process (the left arm of the V-Model in Figure 2), available data will be reviewed, and comments and recommendations provided in order to ensure that the design meets the input requirements and design specifications. This is the verification of the ELEMENT project.

During the design and development process, specific test requirements will be identified to support subsequent validation. Acceptance criteria will be specified by the Design Team and approved by the Verification Team. Acceptance (pass/fail) criteria shall be defined within the test plans at each stage of the verification process. The physical process of conducting testing and reviewing of test data to determine acceptance forms the fundamental aspects of validation, which serves as confirmation that the right product has been developed to satisfy the requirements of the end user.

During the control system design process, systematic development of the control system (starting from a baseline, which is the current turbine controller) will enable incremental improvements to the system until the desired objectives are achieved. The multiphase testing that has been proposed for the ELEMENT project will allow for continuous learning and development, and will facilitate the trialling of many different modes and/or settings to determine optimal control system methodologies. In the earlier stages of the project, many

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different tests may be conducted, with a number of different permutations; however, throughout the progression of the project, and particularly during the latter stages of testing, only minor adjustments will be made.

As the ELEMENT project involves a significant amount of software development (as opposed to hardware design, manufacture, and implementation), the ability to iterate quickly and effectively is significantly enhanced. Initial verification steps may therefore fully verify that the control system software, and implementation thereof, meets with design specifications, but further changes to the control algorithms would be undertaken within the verification stages to iteratively deliver improvements towards the goal of delivering an optimal control system to fulfil the needs of the user (i.e. there will likely be changes to the control system software from that initially verified at the design verification stage). As such, from a software perspective there will not be a "design freeze", however from a control architecture (i.e. the sensors and inputs into the control system) could be considered as reaching a final design freeze prior to the realisation of the optimal coding configuration in how best to utilise the data in controlling the turbine. Once the design verification phase is complete, the identified testing procedures will be used to validate the new control system from component level to system level, and subsequent testing will validate the system in increasingly challenging environments, culminating with testing within an offshore environment similar to that of operational deployment.

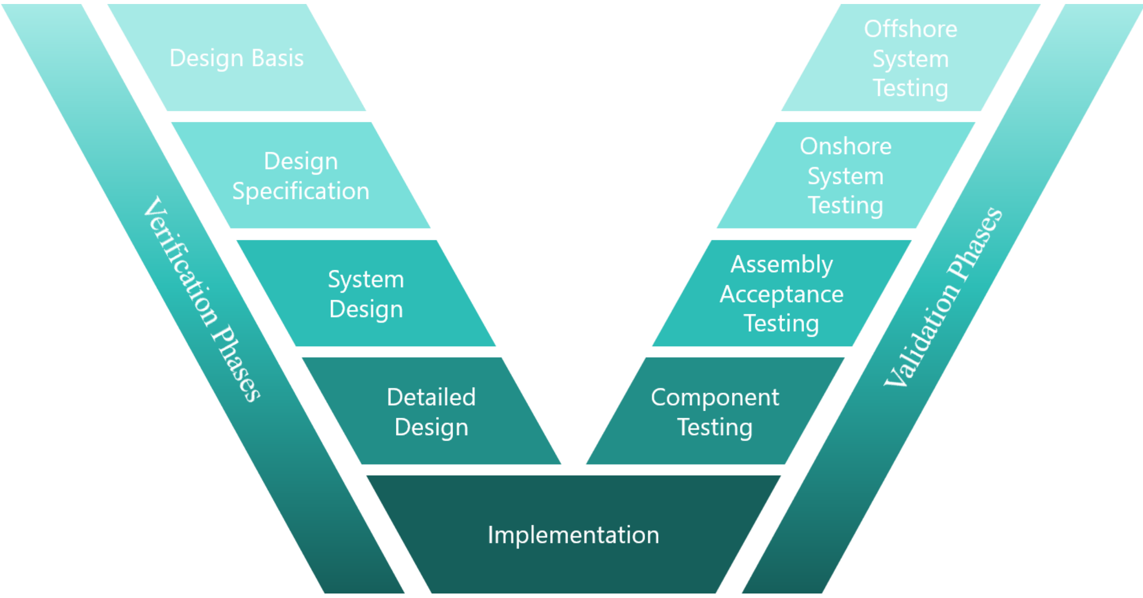


*Figure 2: Verification V-Model*

### 4.1.2. Verification and Validation Methods

Verification consists of assessing the extent to which the system, subsystem, or product fulfils the specific intended functional requirements, and should be supported by documented evidence and robust measurements. Validation consists of checking or proving that the system, subsystem, or product meets the intended use case.

In most cases, verification and validation will involve a combination of methods, with the selection being determined by the degree of novelty and level of technology risk that an item presents. While the product as a whole has to be verified and validated, the verification plan should break this down as required to the level of components, systems, sub-systems, features or materials. An overview of the potential verification and validation methods is presented, in increasing order of complexity:

**Similarity:** If a design uses items that have already demonstrated satisfactory operational performance, meeting or exceeding the requirements within a similar service environment, then evidence to illustrate this similarity may be used to verify a requirement. In addition, minor evolution of a product that has an established track record and is designed to appropriate codes and standards, may also use similarity to verify its conformity to requirements.

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**Design Review:** Where the system is novel, verification of design suitability can be based on a review of the design, the assumptions that underpin it, review of the code used within software to ensure its accuracy, design calculations, and factors of safety within the design calculations against recognised codes and standards, where available.

**Analysis:** Analysis is the verification of a product or system using models, calculations and specialist software. Analysis allows an engineer to make predictive statements about the expected performance of a product or system and is particularly relevant in cases where there are no recognised standards, as analysis is based on fundamental principles rather than developed codes. Analysis can reduce technology risk by providing detailed investigation of specific aspects of the design – for example predicted system response times under specific event scenarios, data dashboarding for visualisation of trends, stress testing (running simulations to identify hidden vulnerabilities), or data analysis to predict the failure mode or time to failure of a component or system. Testing (see below), where required, such as for complex systems, should back up analysis, such as by confirming that the predicted values are observed in practice.

**Inspection:** Inspection involves the direct measurement of an item's attribute(s). For example, if a specification requires that the product is a certain colour, of certain dimensions or within a certain tolerance, or has a certain paint coating thickness, then inspection would be used to confirm that the requirements have been met.

**Testing:** The validation that an item meets the end user's expectations and requirements, using a controlled and predefined series of inputs, data, or excitation (documented within a test plan) to ensure that the item produces the output that satisfies the requirements. Testing will involve the manipulation of the product or system under conditions similar to or representative of those that would be experienced within its intended operating environment. The results of the testing can be assessed to validate whether the system or design performed as expected. Testing should be carried out in a controlled environment to allow repeatability of test conditions.

**Demonstration:** The operation of the item within the complete product prototype, in its intended operating environment. Conditions are no longer simulated but are those that would be experienced by subsequent deployments of the technology. Demonstration activities are generally high cost and can lead to items being damaged in the event of a failure, therefore demonstration activity should only be carried out after significant de-risking through the earlier verification methods.

### 4.1.3. Technical Question Register

The interrogation of information provided during the verification and validation process shall follow a "Claim, Argument, Evidence" approach.

- A **Claim** is a statement, or a requirement of the design, for which compliance or non-compliance can be assessed.
- An **Argument** is to the reasoning in support of a claim. The plausibility of the argument will be reviewed.
- **Evidence** is the information presented in support of a claim, which combines with the argument to demonstrate that the requirements of the claim are fully satisfied.

For example, in the case of a **claim** that a structural component would last for the design life of the product: An **argument** might refer to a recognised design standard, on the basis of which a set of required stress limits and corresponding strain values is calculated. The **evidence** could be: a test report showing that, on the basis of strain gauge data gathered during the test, the specified limits were not exceeded; or a calculation showing that the stress is not exceeded, if an established design method is being used.

During the review of documentation, should any issue be identified which requires clarification, further evidence, or additional analysis in order to fully reduce the risk to an acceptable level, these items will be recorded in a Technical Question (TQ) register. The designers shall address each TQ in a manner that satisfies the Verification Team in order to close the issue. The TQs and expected responses would be expected to be appropriate for the TRL of the control system, or full system in which it is implemented.

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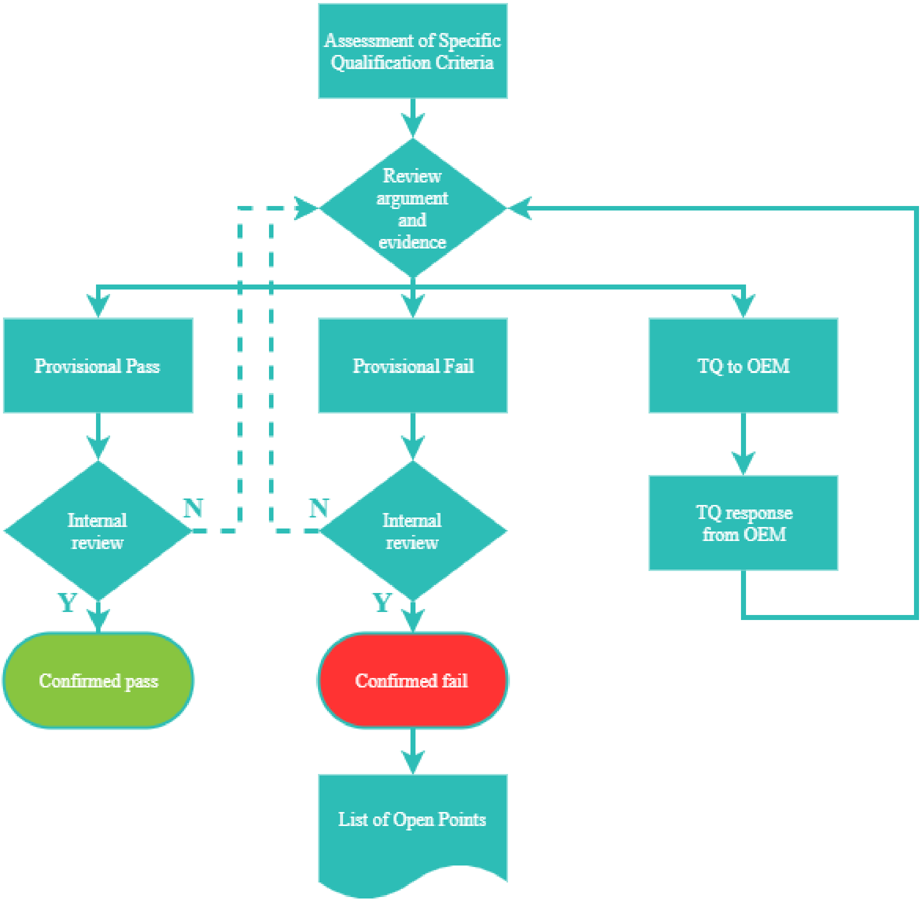


*Figure 3: TQ Process Flow Chart*

### 4.1.4. Non-Conformance / Open Points

If a non-conformance (such as an anomaly, component failure under testing, or a component failing to meet design criteria) is discovered through verification or validation activities, then the root cause must be investigated by the Design Team. The non-conformance could be related to the product, processes, test equipment, facilities, or other external factors.

A Non-Conformance Report (NCR), or a List of Open Points (LOP), shall be relayed to the responsible party so that corrective actions can be taken. NCR/LOPs and associated actions need to be tracked to completion by the developer. If an NCR/LOP results in a design change, the associated verification plans should be reviewed.

### 4.1.5. Current and Emerging Standards

The verification framework is based on the methods outlined in DNVGL-SE-0163 – Certification of Tidal Turbines and Arrays, which provides general requirements for the certification of technology and projects, and DNVGL-SE-0160, which provides an overview of the requirements for Technology Qualification and the management of the qualification and verification process. In addition, the Technology Qualification Recommended Practice, DNV-GL-RP-A203, will be used to ensure that a fully traceable process is used within the context of the ELEMENT project.

The development of ISO standards for the marine energy sector continues, and IEC TC114 are coordinating the preparation of international standards for marine energy conversion systems. While the principal marine energy converter design standard (equivalent to the IEC 61400 wind turbines design standard) is under development, a number of other relevant items of documentation have recently been made available, including IEC TS 62600-4 ED1 - Marine energy - Wave, tidal and other water current converters - Part 4: Standard for establishing qualification of new technology. The Verification Team will continue to monitor developments in these emerging standards.

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## 4.2. Design Verification

The purpose of the Design Verification is to assess and confirm the extent to which the system, subsystem, or product fulfils the specific intended functional requirements outlined within the design specification. In the context of ELEMENT, this will verify that onshore tests meet the objectives of the test plan. This process will be applied to the System Design (WP5) and Behavioural Modelling (WP6) work packages to verify the control system design.

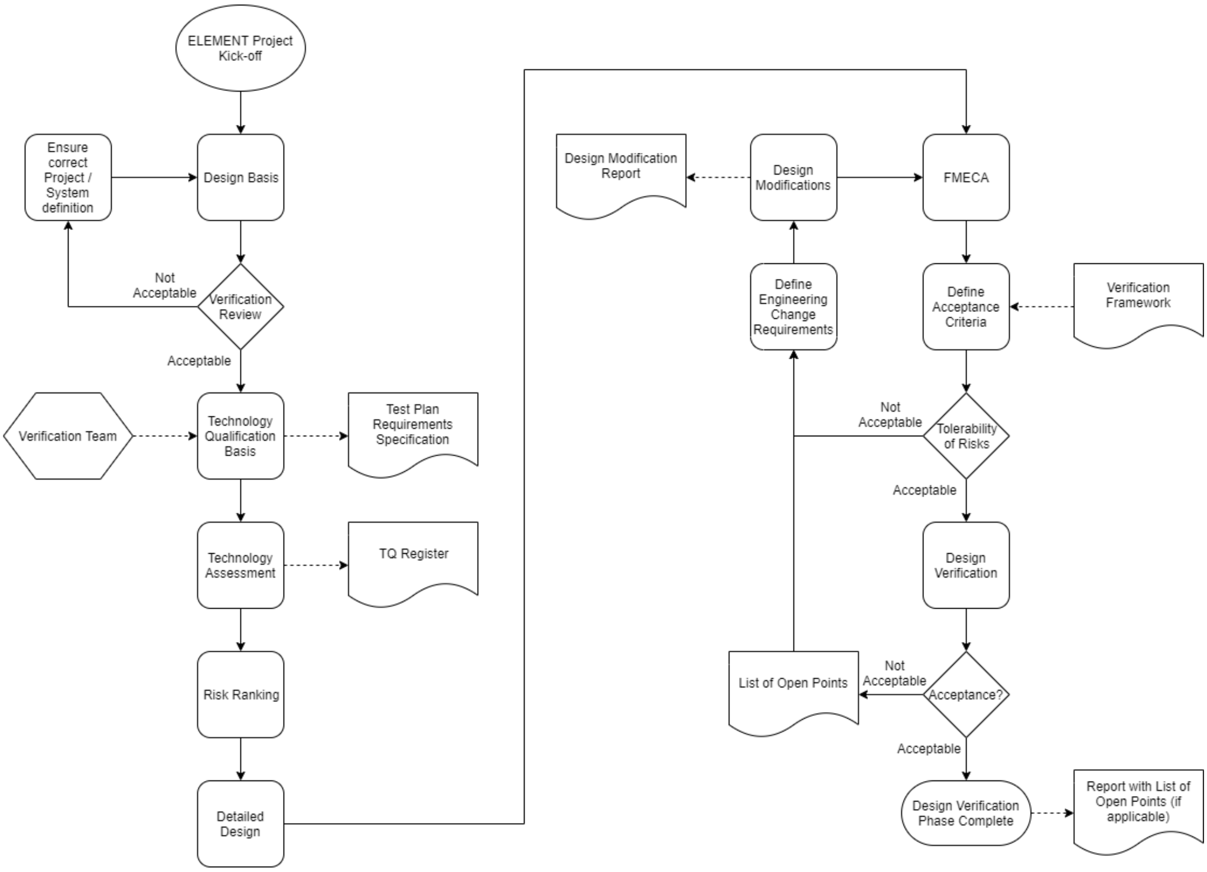


*Figure 4: Design Verification Process Flow Chart*

### 4.2.1. Design Basis

The Design Basis for the turbine controller intended for deployment within the ELEMENT project is currently under development by the Design Team.

The design basis assessment is further defined in DNVGL-SE-0163, section 2.3.2. It refers that this assessment must be able to "provide the key information related to the design, parameters for operation and survival conditions (including accidental scenarios and abnormal conditions)".

Within the ELEMENT project, the Verification Team shall carry out a review of the design basis assessment from a technological standpoint, to assess whether the control system concept is fit for purpose, and to raise any points that may be relevant to design optimisation, technology qualification, or operation of the system.

### 4.2.2. Technology Qualification Basis

The Technology Qualification Basis shall outline the qualification processes to be used to assess conformance with the Design Basis, the verification activities to ensure that all acceptance criteria are met, and the validation activities to ensure that the resulting system meets the intended use case. The Technology Qualification Basis will include aspects of qualification/testing for onshore and offshore testing activity. The qualification basis shall be supported by the test plans associated with the control system, and the wider

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turbine in which the controller is implemented. The Qualification Basis will form the testing plans and acceptance criteria that will be utilised within the validation stages of the project.

### 4.2.3. Technology Assessment

A technology assessment of the existing control system architecture and intended ELEMENT control system will be undertaken to ascertain the aspects of design in which little or no experience exists, or where proven technology has been applied in a novel manner. These are likely to be the areas in which the greatest challenges and uncertainties lie. The first stage of the Technology Assessment process is to:

- Assess the currently available information, with a particular focus on identifying key areas of technical risk.
- Identify areas where the required information to undertake a full technology assessment is not yet available. As the ELEMENT control system will develop and enhance the existing control system, the upgraded control system architecture is still in the design phase, and the availability of documentation is expected to be limited; this should be seen as part of the context of this assessment, rather than an issue of itself.

### 4.2.4. Failure Mode and Effect Criticality Analysis

The responsibility for the development of appropriate Failure Mode and Effect Criticality Analysis (FMECA) and acceptance criteria for all systems and sub systems lies with the designer. The FMECA process will be reviewed by the Verification Team, and comment made as to whether it is felt that risks have been mitigated to an acceptable level. If, during the verification process, additional risks are identified, these shall be reviewed by the Design Team, and suitable mitigation implemented.

### 4.2.5. Documentation review

The Design Team will provide a list of supporting evidence to show that the design requirements have been fulfilled for each sub system. Examples of the types of information that may be considered as relevant for this purpose are provided within the document DNVGL-ST-0164 - Standard - Tidal turbines.

### 4.2.6. Design Verification Report (Confidential)

At the end of the design verification phase, a confidential verification report shall be issued. The detailed verification reports will be confidential, but summaries of the design stage will be made available in the published activity reports for each work package, which will be public deliverables.

The results of the design verification activities shall be reviewed against the specification requirements.

The verification report shall present the overall status of the verification, together with a List of Open Points (LOP), such as any specific requirements that have not been fulfilled, and any design changes that have been made to the ELEMENT control system or turbine within the verification process. A review of the LOP will be conducted at each subsequent stage in testing, to review open points from prior stages of verification, and whether any items can be closed out.

For any points that remain open at the end of the design verification stage, suitable mitigation shall be identified by the Design Team.

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### 4.2.7. Design Final Verification Checklist

*Table 2 Design Verification Evidence and Compliance Reference Documentation*

| Design Evidence Document | Responsible Partner |
|---|---|
| Design Basis, Technical Specifications, and Functional Requirements | Nova Innovation |
| Qualification Basis | Nova Innovation, Wood |
| Technology Assessment (Turbine Control System and associated systems) | Wood |
| Failure Mode and Effect Criticality Analysis | Nova Innovation |
| TQ Register | Wood |
| Qualification Plan for onshore and offshore testing | Nova Innovation |
| List of Open Points | Wood |

## 4.3.Onshore Testing

The purpose of the Onshore Testing is to assess and confirm that the system, subsystem, or product meets or exceeds performance expectations in an onshore laboratory environment. In the context of ELEMENT, this will verify that onshore tests meet the objectives of the test plan. This process will be applied to the Onshore Testing (WP8) work package to verify and validate the system performance.

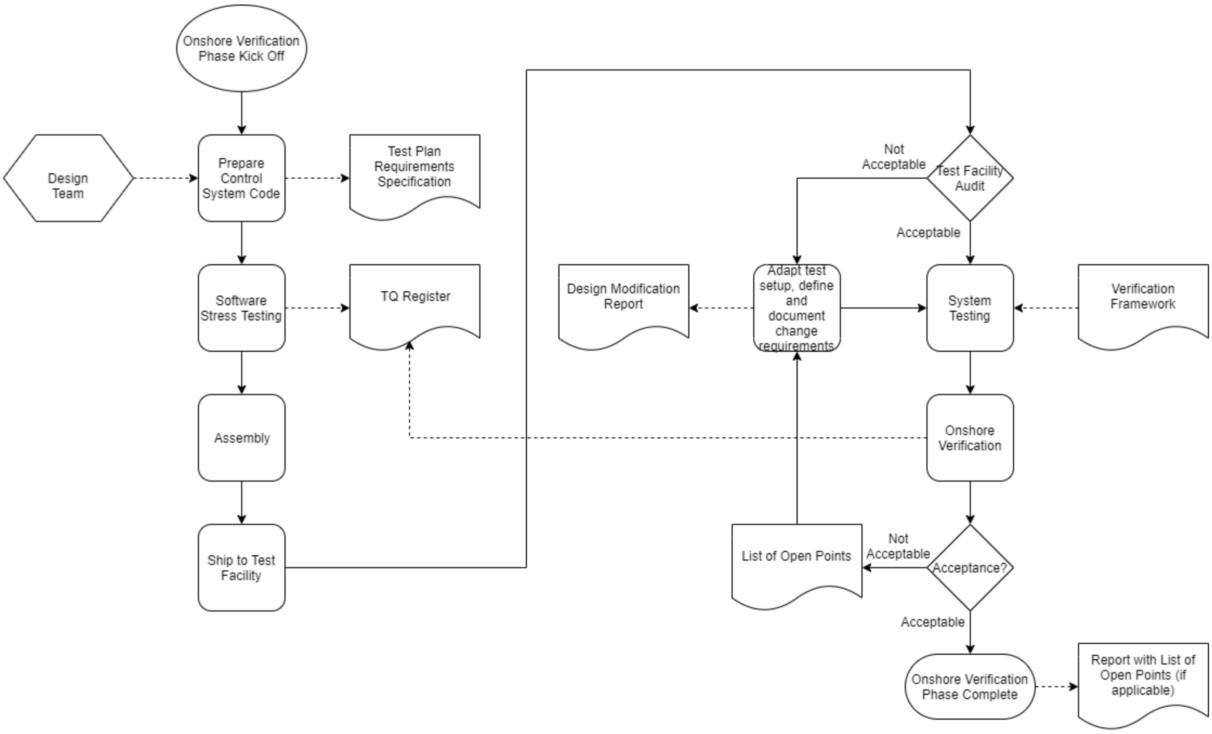


*Figure 5: Onshore Testing Verification Process Flow Chart*

### 4.3.1. Testing

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 815180.

The onshore testing offers a test environment where there is controllability, repeatability, and full system and actuator calibration. The onshore testing will take place at an accredited test facility in the UK, with a tidal turbine drivetrain test rig.

The onshore testing will comprise the following steps:

- Identification of necessary tools (test rig, sensors, hardware, software)
- Set up test equipment
- Commission test system
- Run tests
- Analyse test results

Test plans will be prepared in advance of the onshore testing phase, with all test requirements identified and itemised. The completion of these tasks shall be described at a high level in deliverable D8.1 Onshore System Test Report.

### 4.3.2. Verification of Testing Procedures (Test Program Verification Audit)

The test facility shall be responsible for ensuring that adequate quality control procedures for monitoring the validity of test results and calibrations is in place. In order to gain comfort in the quality and competence of the test facility staff, the robustness of general test procedures carried out within the facility, and the quality of the results generated, an audit of the facilities will be conducted. The audit will be for internal reference purposes only, and the output will not be required as a deliverable within the scope of the ELEMENT project. This audit will be carried out by the Verification Team, and shall include a review of the following factors:

- Human factors (staff, training, CVs).
- Accommodation and environmental conditions (controllability of test environment).
- Test and Calibration Methods (identification of the accuracy and uncertainty of measurements taken by sensors and data acquisition equipment).
- Measurement Systems Analysis (establish the capability of the test facilities and test rig, what are the limits. Note: MSA should consider the following parameters: Bias, Linearity, Stability, Repeatability, and Reproducibility).
- Itemised equipment list, certificates of conformity, and calibration certificates.
- Measurement traceability (relating calibrated measurements at the test facility to reference measurement units of the international SI (Système International d'unités) system of units, through a documented unbroken chain of calibrations or comparisons).
- The handling of test and calibration items (Procedures should be in place to ensure the integrity, safety, and security of test items during transport, handling operations, receipt of goods, storage, retention, and return of items).

### 4.3.3. Validation of Results

The results of the testing shall be analysed in detail in order to validate the control system. The main goals of the onshore testing are to:

- Validate the onshore "Hardware in the Loop" (HiL) testing of the upgraded turbine drivetrain using the OREC tidal energy test facility at Blyth, UK. HiL is required to provide realistic representation of the feedback loop between the control system and blade performance, allowing demonstration of the performance of the ELEMENT control system in a realistic variable flow regime; and
- Verify the ELEMENT control system performance in a controlled environment, across a range of tidal flow speeds and turbulence characteristics.

The above will be carried out in line with the Qualification Basis.

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### 4.3.4. Verification Report (Confidential)

At the end of laboratory testing verification, a confidential laboratory testing verification report shall be issued. The verification report shall present the overall status of the verification, together with a List of Open Points (LOP), such as any testing requirements that have not been fulfilled, and any design changes that have been made to the ELEMENT control system within the verification process. The LOP from the Design Verification phase should then be reviewed to see where data from the testing, or data from other project WPs, may have provided additional information that will allow the close out of open points.

For any points that remain open at the end of the verification stage, suitable mitigation shall be identified by the Design Team.

The test results shall be reviewed against the test requirements. Thereafter, the test results shall be interpreted to assess what they mean in terms reliability and performance requirements against the desired target metrics and objectives.

The Verification Report will identify key areas that should be the target of future testing, in order to increase confidence in the control system's performance, and the overall ability to demonstrate technical performance in line with target metrics. Secondly, the report shall highlight areas in which the test program has already led to high confidence in modelling and / or results.

### 4.3.5. Onshore Testing Final Verification Checklist

*Table 3 Onshore Testing Verification Evidence and Compliance Reference Documentation*

| Design Evidence Document | Responsible Partner |
|---|---|
| Test Facility Audit (to be included within the Onshore Verification Report) | Wood |
| Assembly Acceptance Test Certificate to confirm that the full assembled ELEMENT system has been commissioned. | Nova Innovation |
| Test rig and test set up is in conformance with the test plan. | Verification Team |
| Signed Test Completion Checklists (Filled out as per tests required in ELEMENT onshore test specifications). | Nova Innovation, ORE Catapult |
| Test data quality control verification. (Quality Control conditions TBC). | Verification Team |
| Updated TQ Register | Wood |
| Updated Qualification Plan for offshore testing | Nova Innovation |
| Updated List of Open Points | Wood |

## 4.4.In-sea Testing

The purpose of the In-sea Testing is to assess and confirm that the system, subsystem, or product meets or exceeds performance expectations in environments representative of the operation of the eventual commercial product. This process will be carried out in three phases: Tow Testing (WP9), Estuary Testing (WP10), and Offshore Testing (WP11). Each relevant work package will be reviewed to verify and validate the system performance.

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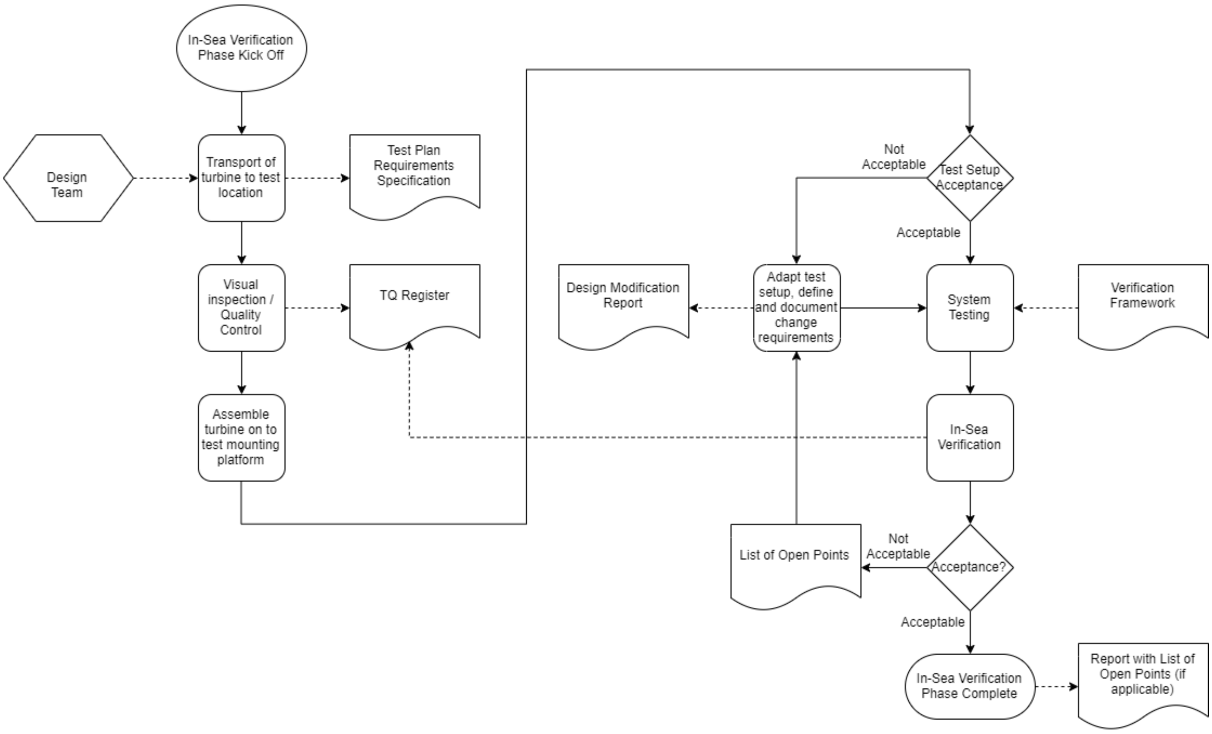


*Figure 6: In-Sea Testing Verification Process Flow Chart*

Tow testing is carried out as a quick and very efficient way of applying real hydrodynamic loading to a turbine. This allows the full system to be tested for the first time, while retaining the ability to adjust the boat speed to mimic different tidal flow speeds. Estuary and Offshore testing provide the opportunity for real-world operation and learning in a staged approach to increasing the complexity of the testing environment. It should be noted that, unlike the onshore testing, in-sea testing will be conducted within environments that are not controllable. This means that repeatability of testing cannot be provided in the same manner as can be conducted in the onshore testing – it will not be possible to recreate exactly any testing activities already carried out, nor to expect identical results from similar test runs in the offshore environment. This must be considered when verifying the testing results during the in-sea test phase.

### 4.4.1. Test Plan

A test plan will be created for each phase of testing, and will form part of the Qualification Basis, as discussed in Section 4.2.2. These documents will outline the main tests and expected outcomes at each test phase.

### 4.4.2. Testing

The in-sea testing offers a test environment where the system will face conditions representative of that of a device deployed on a commercial basis. The in-sea testing will take place at three separate locations, but the principles of each test campaign will be broadly similar (with the turbine operating in different flow conditions, and attached to a different support structure in each case).

The in-sea testing will comprise the following steps:

- Identification of necessary tools (turbine mounting platform – i.e. tug-boat mounting, moored platform, or seabed foundation. Sensors, hardware, and software);
- Set up test;
- Commission test - Run initial commissioning tests to verify the performance of the test system;
- Run in-sea test - Deliver the test plan. Decommission test equipment on completion; and
- Analyse test results - Assess test results and performance of control system. Identify potential refinements to behavioural model and control system design. Modify subsequent testing programme if required.

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An overview of these tasks shall be detailed in a dedicated test report for each test phase.

### 4.4.3. Validation of Results

The results of each phase of in-sea testing shall be analysed in detail in order to validate that the system performance meets with functional requirements and fully satisfy the performance requirements of the end user. This will be carried out in line with the Qualification Basis.

### 4.4.4. Verification of Testing Procedures (Test Program Verification Audit)

Test procedures shall be followed explicitly. While testing may not be repeatable, conformance with the test plan is mandatory. If, during any verification or testing activities, it is discovered that processes or procedures require modification, then any changes shall be documented, and the necessary approvals obtained, before continuing with the testing and verification process.

The test programme shall be verified by confirming that all tests required within the test plan have been carried out. The Design Team shall compile a specific test checklist for each for each item from the test plan and identify completion criteria. These test checklists shall be completed for each test undertaken, to identify progress within the offshore system test programme. Individual test completion shall be recorded on the checklist and signed off by appropriate personnel from the test centre and Nova Innovation.

The Verification Team will carry out an audit of the test to ensure that testing is carried out in compliance with the test plan, and that appropriate/accurate data collection is taking place. Tests witnessed by the Verification Team shall be recorded on the test checklist for traceability. Data from test results shall be reviewed by the Verification Team to ensure that they are of sufficient quality from which to draw reliable conclusions for each of the test needs identified in the test plan(s). Suitability of the vessel for tow testing, and for achieving the desired conditions to meet the requirements of the test plan shall be confirmed.

### 4.4.5. Verification Report (confidential)

At the end of each phase of in-sea testing (tow testing, inshore/estuary testing, and offshore testing), a confidential verification report shall be issued. The detailed verification reports will be confidential, but summaries of each test stage will be made available in the published activity reports for each work package, which will be public deliverables.

The test results shall be reviewed against the test requirements. Thereafter, the test results shall be interpreted to assess what they mean in terms reliability and performance requirements against the desired target metrics and objectives.

The verification reports shall present the overall status of the verification, together with a List of Open Points (LOP), such as any testing requirements that have not been fulfilled, and any design changes that have been made to the ELEMENT control system or turbine within the verification process. The LOP from the Onshore Verification phase should be reviewed during the In-Sea testing phase to see where data from the testing, or data from other project WPs, may have provided additional information that will allow the close out of open points. A similar process will be conducted at each subsequent stage in testing, to review open points from prior stages of testing, and whether any items can be closed out.

For any points that remain open at the end of the verification strategy, suitable mitigation shall be identified by the Design Team.

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### 4.4.6. In-Sea Testing Final Verification Checklist

*Table 4 In-Sea Testing Verification Evidence and Compliance Reference Documentation*

| Design Evidence Document | Responsible Partner |
|---|---|
| Commissioning Report | Nova Innovation |
| Offshore test rig, turbine mounting system, vessel or moored platform (if applicable), and offshore test facility audit | Wood |
| Test programme verification audit | Verification Team |
| Signed test completion checklist | Nova Innovation |
| Test data quality control verification. (Quality Control conditions TBC). | Verification Team |

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# 5. CONCLUSION OF VERIFICATION ACTIVITIES

The verification activities described in this document are based on learning gained from industry best practice, and standards developed by DNV-GL. This document is also based on previous experience that the Verification Team has gained from participation in tidal energy projects and the undertaking of relevant verification activities.

At the conclusion of the verification work package, five confidential reports will have been issued, one for each stage of the verification process (design, onshore testing, tow testing, estuary testing and offshore testing), ensuring traceability of the technical assessment and reporting at each stage of the verification process. Summaries of each test stage will be made available in in the public activity reports for the associated work package. In addition, the TQ register and LOP will remain live documents to be updated throughout the course of the project.

It is the aim of the consortium that, by having followed the Verification Framework throughout the life of the ELEMENT project, the control system will have achieved significant de-risking. The activities carried out under the Verification Framework will provide a measure of the confidence in ability to bring the technology through further iteration and development beyond current technology stage.

This published report provides an outline of the verification plan at the start of the project. Within the project, any changes to the verification activities will be reflected in the verification reports, and summarised in the public reports for each work package.

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