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Project acronym: INNOQUA

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D3.1 – Test Plan

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Document history

History			
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1	07.09.2016	EUT	1st draft version of the index
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3	10.11.2016	NBK	ETV Program content
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6	23.11.2016	NBK, SUEZ, NUIG	Full revision with contributions and suggestions
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8	29.11.2016	EUT	Final version (1st iteration)
9	26.07.2017	NUIG, R2M	Pre-Market and technical requirement compliance Enhancement
10	30.07.2017	EUT	Update of the document
11	07.08.2017	INB	Heat transfer analysis content
12	15.08.2017	NBK, SUEZ, NUIG	Full revision with contributions and suggestions

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Executive Summary

The aim of the INNOQUA Project is to progress, towards commercialisation, the development of a fully ecological modular sanitation system that integrates individual low cost, sustainable and biologically based technologies. The system will offer flexible waste water treatment solutions to suit a variety of target markets in developed and developing countries.

This report, Deliverable 3.1 (D3.1) Test Plan, is the final iteration of the report of subtask 3.1.1 "*Test Plan* from the Project's Work Package (WP) 3 – "*Technology integration, eco-design and pre-industrial scale up*" and it corresponds with the outcome of subtask 3.1.1 "*Test Plan*".

The goal of D3.1 is to provide a comprehensive report outlining how the INNOQUA early models will be evaluated throughout the project to achieve a robust solution that complies with pre-market requirements defined in WP1 and technical specifications defined in WP2. Therefore, this document presents a common framework based on a triple assessment: *(i)* engineering and operational; *(ii)* environmental and *(iii)* pre-market requirements compliance.

The engineering and operational assessment is focused on load, stress and capacity tests of the ICT architecture, numerical simulations of the designs and real simulations of the micro-biological behaviour of the living organisms.

The environmental assessment is based on Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) analysis to address the INNOQUA solution towards a sustainable solution and the ETV Program (Environmental Technology Verification Program) to evaluate the effectiveness of the INNOQUA solution by a credible recognised verification procedure.

The last assessment, the requirements compliance, is focused on checking the compliance with the pre-market requirements and technical specifications collected throughout WP1 and WP2 respectively.

This final last iteration of this deliverable D3.1 (M15), it has been enhanced from the preceding by the introduction of new engineering tests such as the heat transfer analysis. Moreover, the document has been refined improving the descriptions referred to engineering and operational assessment and requirements compliance assessment.

1 Introduction

The aim of the INNOQUA Project is to progress, towards commercialisation, the development of a fully ecological modular sanitation system that integrates individual low cost, sustainable and biologically based technologies. The system will offer flexible waste water treatment solutions to suit a variety of target markets in developed and developing countries. The INNOQUA project commenced in June 2016 (M01) and this report, Deliverable 3.1 "*Test Plan*" (D3.1), is the last iteration of itself from the project's Work Package 3 (WP3) "*Technology integration, eco-design and pre-industrial scale up*".

1.1 Work Package 3 Objectives

The goal of WP3 is firstly to prepare all the materials and documentation for the elaboration of the system prototypes (WP4) and system demonstrators (WP5) based on the previously defined specifications (WP2). More specifically, the detailed objectives of this Work Package are to: *(i)* design and validate virtual models & prototypes which will be built in WP4; *(ii)* optimise the technical parameters of the proposed design options; and *(iii)* assess and optimise the environmental and economic impacts of the INNOQUA system with life cycle approaches. Ultimately, the goal of WP3 is to satisfy Project Milestone MS2 in defining the First prototypes and MS3 assessing the performance before demonstration. The Project Milestones, Deliverables and Work Packages are fully described in Annex 1 (Part A) of the European Commission Grant Agreement Number – 689817- INNOQUA Description of Activities (DOA) documentation (European Commission, 2016).

1.2 The role of Deliverable D3.1

The goal of D3.1, which corresponds with the outcome of subtask 3.1.1, is to provide a comprehensive report with the definition of a common framework to be followed throughout of the INNOQUA project encompassing multiples assessments ranging from numerical simulations (T3.1.2 "*Numerical Model and Simulation*") to real experimentation (T4.3 "*Small-scale field testing*") including environmental analysis (T3.1.3 "*Simplified LCA & LCC*") and ensuring their right operations and the strong alignment of the technologies with the requirements defined on WP2.

1.3 Relationship with other Activities in the Project

This deliverable has a key role in the technical assessment of the INNOQUA designs thanks to the virtual assessment of the designs.

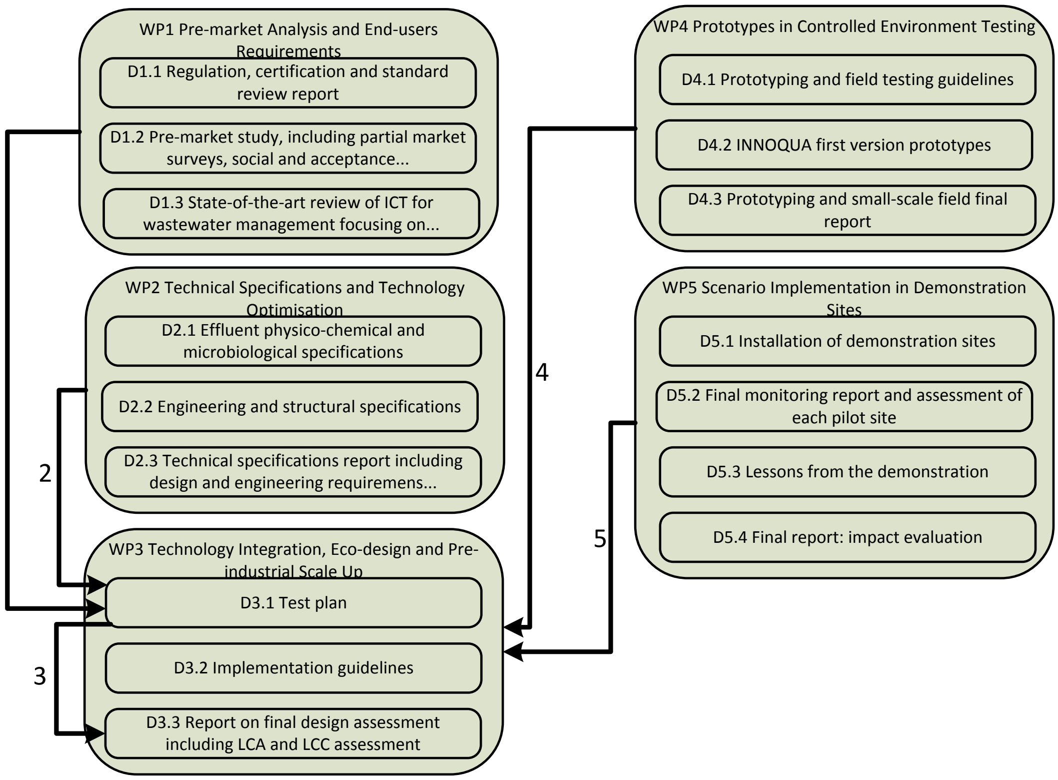

Figure 1: Relation with other WPs and Deliverables

Figure 1 illustrates the relationship of between this deliverable and other activities in the INNOQUA project. These relations are represented as links numbered from 1 to 5 and are described as follows:

Link 1 and 2: The test plan includes a relevant assessment focused on checking the pre-market and technical requirements compliance. Therefore, this deliverable is fed by the technical and pre-market requirements from WP1 and WP2 deliverables'. Moreover, the major part of the analysis takes advantage of the designs defined throughout WP2 including engineering and ICT designs.

Link 3: The outcome of all simulations and all design criteria and associated influence on final system design will be presented on D3.3 "*Report on final design assessment including LCA and LCC assessment*".

Link 4 and 5: The feedback extracted from the outcomes of controlled environment testings (WP4) and demonstration sites (WP5) will be used to optimize the INNOQUA designs. These changes will be updated in the virtual models in order to validate them.

1.4 Approach to the Development of D3.1

To progress the development of Project Task T3.1.1, EUT prepared the D3.1 Table Of Content (TOC) with the responsible and the description of the expected content for each section and subsection which was uploaded to the Project Emdesk. It facilitated the collection of data during the first iteration.

The approach and scope of the second iteration of D3.1 were discussed taking advantage of the periodic WP3 meetings. The content was also collected by using Project Emdesk

1.5 Document Outline

In line with the requirements of the project Grant Agreement and Work Package Descriptions, this report includes:

a) a detailed description of the testing framework;
b) an exhaustive description of the assessments related to the INNOQUA operation and engineering;
c) a description of the assessments related with to environmental and economic aspects of the INNOQUA solution based on LCC & LCA and ETV program;
d) a description of the assessment process to check the pre-market and technical requirements compliance; and
e) conclusions and future work.

2 Testing framework

The main aim of the testing procedure is to optimise the INNOQUA module designs proposed throughout the WP2 and align them to the market by using virtual models. Then, the testing procedure provides the guidelines to evaluate the models generating design recommendations and suggestions throughout of Task 3.1 “Early models and assessment” and Task 3.2 “Optimisation”. It is an assessment common framework that is based on a triple assessment: *(i)* operational and engineering evaluation to ensure the right operation of the solution and its design from the engineering point of view; *(ii)* environmental and economic analysis to minimise the environmental impact of the solution by applying sustainable design decisions; and *(iii)* pre-market and technical requirements compliance to ensure that the solution satisfies the requirements defined on WP1 and WP2 (pre-market and technical).

Below, the testing procedure introduced in the Figure 2 is depicted. Initially, the virtual models designed in the WP3 allows assessment of INNOQUA designs in three different ways such as operational & engineering (see Section 3), environmental & economic (see Section 4) and requirements compliance (see Section 5). These evaluations will provide a number of recommendations and design suggestions such as consider designs that employ gravity feeds over pumped supplies or use local construction materials next to the destination to minimise the carbon footprint of installations… All these recommendations will be depicted in the D3.3 “*Report on final design assessment including LCA & LCC assessment*”. Once the designs are updated by the application of previous recommendations and suggestions, they are evaluated again. Subsequently the WP4 and WP5 also provide recommendations and suggestions thanks to the real experimentation with the INNOQUA solution which are applied in the designs once more.

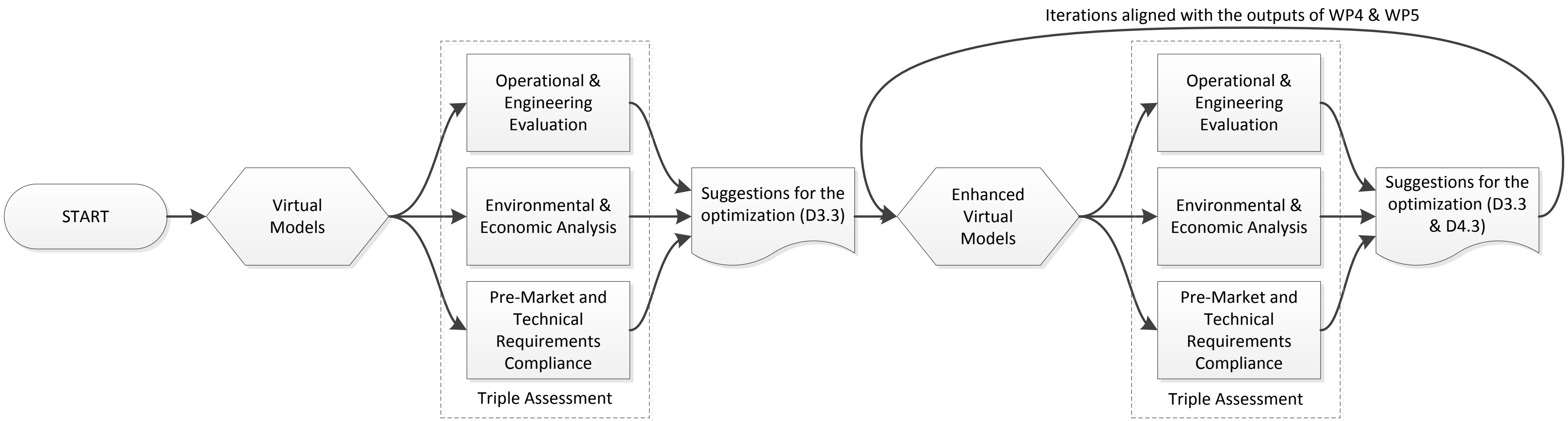

Figure 2: Diagram of the testing framework

It is important to note that this procedure allows the assessment of INNOQUA solution from a virtual approach ranging from design to end-use. It aims to achieve designs more optimised and aligned with the requirements defined in the WP1 and WP2 by using the knowledge extracted through the simulation.

3 Operational and Engineering Evaluation

This section collects the definition of the tests aligned with the first step of the triple assessment, operational and engineering evaluation. Mainly, these tests are classified in three subjects: *(i)* engineering assessment (see Section 3.1); *(ii)* microbiological assessment (see Section 0) and *(iii)* ICT assessment (see Section 3.3).

The engineering assessment is focused on a Computational Fluid Dynamic (CFD) analysis of the daphniafilter tanks (see Section 3.1.1), the structural analysis for the daphniafilter and lumbrifilter tanks (see Section 3.1.2) and the heat transfer analysis of the lumbrifilter and daphniafilter Tank (see Section 3.1.3). The microbiological assessment will be based on real-experimentation throughout the WP2 and WP4 (see Section 3.2) because currently the daphniafilter and lumbrifilter technology cannot be simulated due to their novel nature. Moreover, the real experimentation will provide more accurate results and less expensive that the computational simulation of the microbiological characteristics of the technologies.

The CFD of the lumbrifilter Tank has not been considered due to the complex nature of the filtering process and the lack of correlation between filter efficiency and any relevant fluid dynamic parameter. Also, it is important to note that the technologies are treated as individual modules during engineering assessment because they are seen as an inflow and outflow. The assessment of the whole solution will be performed with real experimentation throughout WP4 and WP5.

Finally, the ICT assessment is focused on evaluating the Monitoring and Control Unit (see Section 3.3).

3.1 Engineering Assessment

This section is dedicated to present the tests related with engineering, structural and mechanical aspects of INNOQUA component design. Mainly, the tests are based on conducting numerical modelling and simulations to address the designs meeting WP2 and WP3 requirements.

The Figure 3 presents the engineering assessment process defined in this first iteration of the test plan.

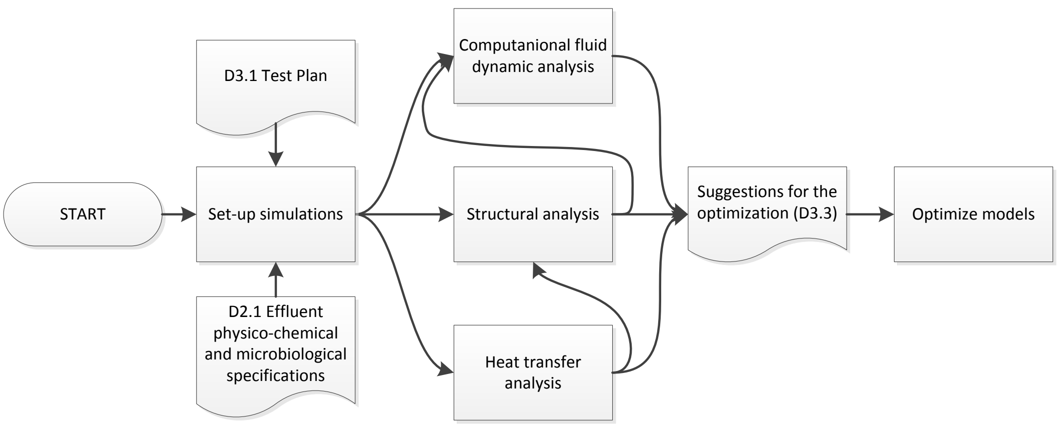

Figure 3: Engineering assessment process

Basically, the evaluation process will take advantage of the outcomes of D2.1 "*Effluent Physico-Chemical and Microbiological Specifications*" and D3.1 "*Test plan*" to set-up the simulations and perform the following assessments: *(i)* computational fluid dynamic analysis of the daphnia tank; *(ii)* structural analysis of the tanks (daphnia and lumbrifilter); and *(iii)* heat transfer analysis of the tanks (daphnia and lumbrifilter). Finally, the outcomes of these analysis are presented in the D3.3 and used to optimise the models.

It is important to note that the material selected for the daphniafilter a lumbrifilter tank construction (e.g. HDPE) is a key factor in the structural and heat transfer analysis of the unit and it is used as input data in both analyses. Therefore, any proposed change to the construction material or internal tank structure/design (e.g. as modification following structural analysis) will require a new computational fluid dynamic analysis, structural analysis and heat transfer analysis.

3.1.1 Computational Fluid Dynamic Analysis of the Daphniafilter Tank

The Computational Fluid Dynamic analysis is carried out throughout the subtask 3.1.2 and 3.2.2 and presented in the D3.3 "*Report on final design assessment including LCA and LCC assessmen*t". It optimises the critical fluid dynamic aspects enhancing the efficiency of the biological system.

Boundary conditions

The numerical simulations will be carried out assuming a range of boundary conditions defined by the key elements listed below.

- Influent relevant conditions (into Daphnia Filter):
  - Water inlet temperature: 8 - 25 degC. According to the favourable temperature conditions for the Daphnia survival (Pau et al., 2103; Serra et al.,2014; Burns 1969; Schalau et al., 2008). According to the change in temperature from 8 to 25 we could search the maximum and minimum water density and justify why we have decided to consider the density of 998.
  - Water inlet density assumed constant as 998 kg/m3 (temperature influence and water biological contents is negligible)
  - Water viscosity: function of temperature
  - Available intake flow particle characteristics:
    - Density: 1.05 g/cm3
    - Volumetric concentration by size (data provided by UdG refer to Fig below)

The particle size distribution presented in Figure 4 presents the particle volume concentration versus their diameter of each particle size measurable by the LISST-100x (from 2.5 μm to 500 μm). The LISST-100x uses the diffraction theory of the light to analyse the light pattern of the laser that arrives at a detector after travelling though the sample (consisting of a suspension of particles. The particle volume concentration has units of $\mu l\ l^{-1}$, representing the volume occupied by the particles (in ml) in a litre of sample. The particle size distribution here presented corresponds to the analysis of a water sample obtained from Lombritek station at the outlet of the Lumbrifilter. The vertical dashed line in Figure 4 highlights the maximum diameter of particles that can be ingested by Daphnia, as indicated by Burns (1969) and Pau et al. (2013).

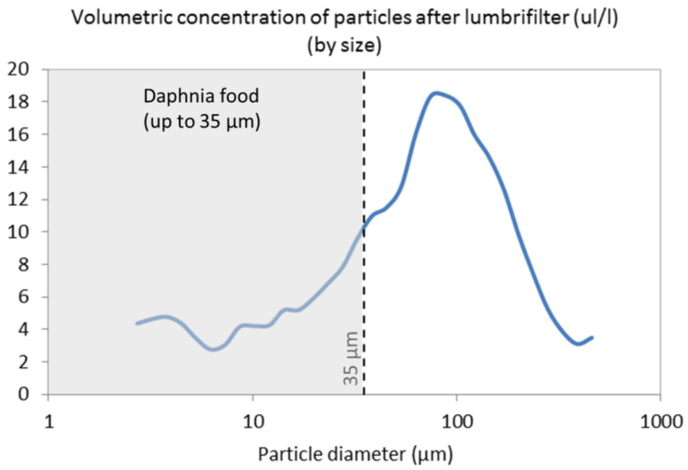

Figure 4: Volumetric concentration of particles after Treatment by Lumbrifilter

- Flow rate conditions:
  - Average flow rate: 1.5 m3/day
  - Variability of intake flow rate: (effective inflow time/total time ratio): 50% / 25% / 10% e.g. 25% means that the daily volumetric flow will have entered the tank in just 6 hours, the remaining 18 hours there won´t be any flow intake. This ratio is considered to take into account flow intake velocities that are higher than the ones obtained assuming an average constant flow intake all day long.

Design specifications

Based on the experience of UdG scientific team, the following aspects have been identified as critical to obtain the best living and performance conditions for the Daphnias and will be considered as design specifications.

- Maximum local velocity: 3.5 mm/s
- Ideal mean flow velocity: 1 mm/s
- Maximum average ascending flow: 0.17 m/h (according to a hydraulic retention time of 6h, Serra and Colomer, 2016)
- Ascending flow uniformity
- Minimum and Maximum local water temperature
  - Vital temperature range for Daphnias: 8 – 25 degC
  - Comfort temperature for Daphnias: 18-21 degC (Pau et al., 2013; Serra et al., 2014)
- Peripheral outlet flow uniformity
- Promote high concentration of particles below 35 µm on sunlight areas
- Promote a region with relatively static flow on the lower part of the tank to promote sedimentation of large diameter particles.
- Avoid preferential flow paths of high velocity that could drag daphnias out of the tank.
- Understand the dynamic of sedimentation of big diameter particles

Main design parameters

The simulations will help optimise the main design parameters listed below:

- Tank overall size
- Tank overall shape
- Tank bottom collector shape
- Internal deflectors geometry, positioning and number
- Tank feeder (water intake strategy)
- Tank overflow geometry
- Tank heat exchange (non-steady analysis required)

Simulation approach

The simulations will be carried out using state of the art CFD software (Ansys CFX/Fluent) coupled with 3D modelling tools (Solid Works). Numerical and graphical information will be obtained to support design choices.

The simulations will follow a strategy of increased complexity path as shown in the diagram below (see Figure 5) to maximise resources and to tackle the needs at each stage of the design in the most efficient way. The next table presents the main details, inputs and outputs of each phase.

Table 1: Simulation strategy for computational fluid dynamic analysis

	Phase 1	Phase 2	Phase 3
	Quasi 3D simulations	**Full 3D simulations**	**2D / 3D simulations**
Main details	2D axisymetry 3D periodic Steady state	Fully detailed 3D geometry Steady state	Particle analysis Multiphase flow analysis Unsteady
Inputs	Tank main dimensions Overall design requirements	Fully detailed 3D geometry Phase 1 outputs Local design requirements	3D Geometry Specific design requirements
Outputs	**- Mean velocities** **- Tank main geometry** **- Key element positioning**	**- Detailed flow characteristics** **- Detailed component sizing**	**- Particle density by size** **- Sedimentation efficiency** **- Tank inserts geometry**

Increased complexity, computational time and resource needs

Design maturity

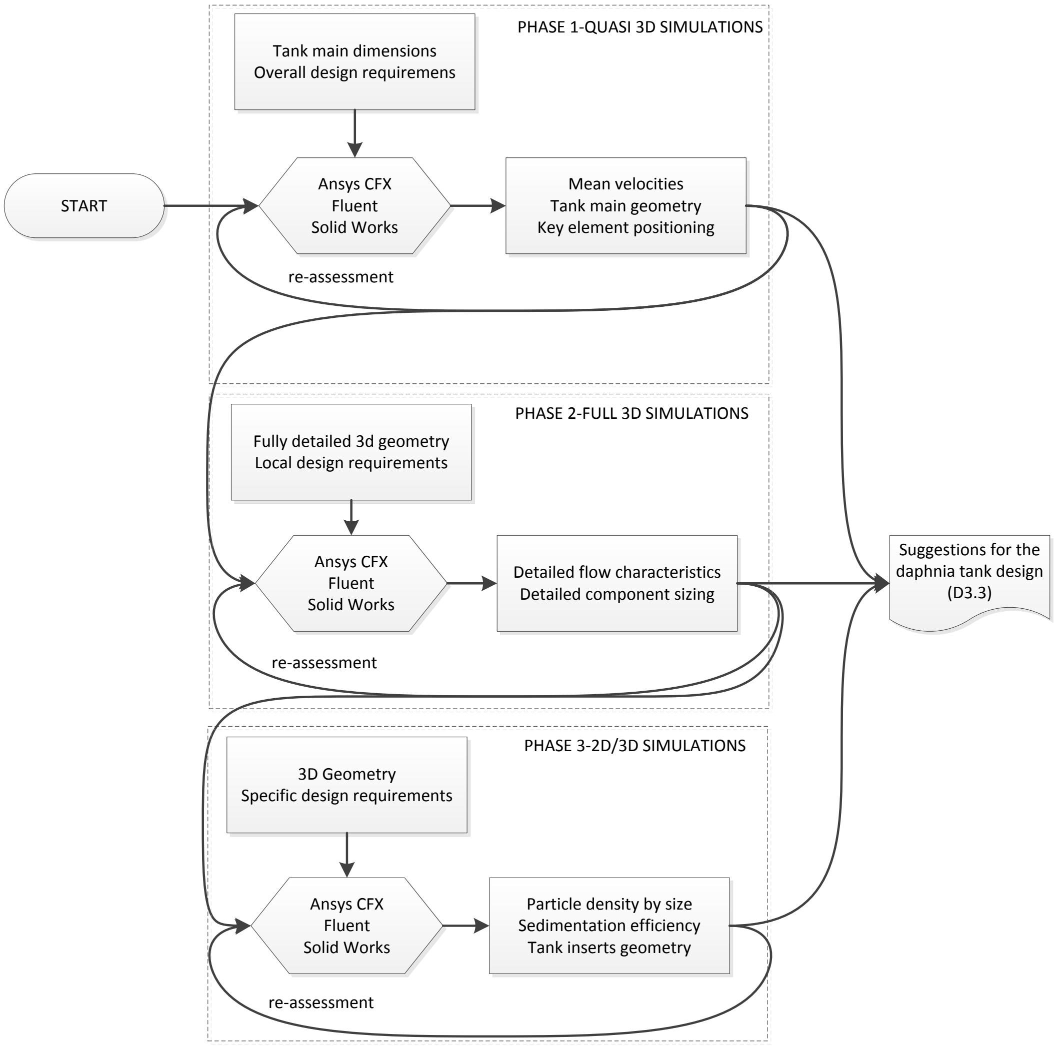

Figure 5: Computational fluid dynamic analysis process

3.1.2 Structural Analysis of the tanks

Structural analysis is carried out to optimise shapes and to size the main components of the mechanical system to ensure the most cost effective solution is chosen while meeting the structural requirements. This analysis will be performed for both, the Lumbri tank and Daphnia tank. The latter analysis will be done in parallel with the fluid dynamic analysis.

Design requirements

The main design requirements taken into account for the mechanical analysis are listed below:

- Material choices (stress limits, manufacturability)
- Maximum deflections allowed (material dependency)
- Overall dimensions (volume, system constraints)
- Logistics
- Handling and installation
- Cost

Design parameters

The design parameters to be optimised by the structural analysis are:

- Detailed shapes
- Wall thickness

Simulation approach

The simulations will be carried out using state of the art Finite Element Method software (Ansys Mechanical) coupled with 3D modelling tools (Solid Works). Numerical and graphical information will be obtained to support design choices.

Below, the steps to perform the simulation are listed:

1. The first structural analysis will be carried out with a fully defined 3D geometry of the tank after completing phase 3 of the fluid dynamic analysis.
2. An optimisation process will follow to reduce stress levels to acceptable limits without affecting the inner shape hence not disturbing the fluid dynamics of the system.

It is important to note that only if the inner geometry has to change another iteration will be needed on the fluid dynamics analysis.

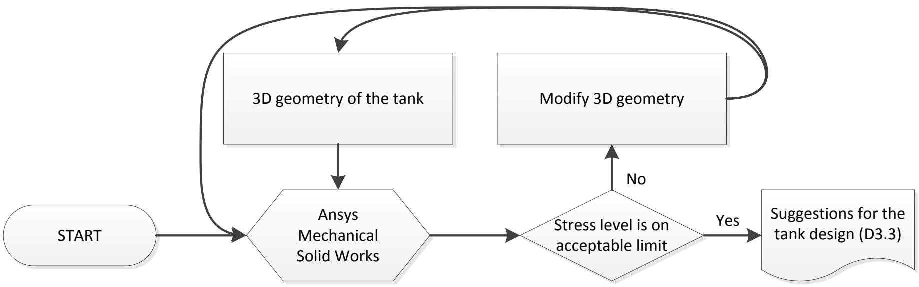

Figure 6: Structural analysis process

3.1.3 Heat Transfer Analysis

There is a wide spectrum of ambient conditions and system load characteristics depending on the test location in terms of air and water temperatures, sun hours and radiation and flow rates required. Hence it is deemed necessary to carry on a comparative analysis to evaluate the best installation conditions of the protype tanks depending on its location to maximize the filtering efficiency of the system. For this purpose a heat transfer analysis will be carried out as per details below.

3.1.3.1 Daphnia tank

Design requirements

It is of the utmost importance to ensure that the daphnia tank water temperature stays within the limits defined below to ensure maximum filtering efficiency.

- Vital temperature range for Daphnias: 8 – 25 ºC
- Comfort temperature for Daphnias: 18-21 ºC

Design variables

The main design variables taken into account for the heat transfer analysis are listed below and depicted in Figure 7.

- Thermal conductivity
  - Material choices
  - Tank shape and size
  - Tank installation (Above ground / underground)
- Ambient conditions: sun hours, sun radiation, air temperature (variable depending on test site)
- Inlet flow temperature (variable depending on test site)
- Inlet flow rate (variable depending on test site)

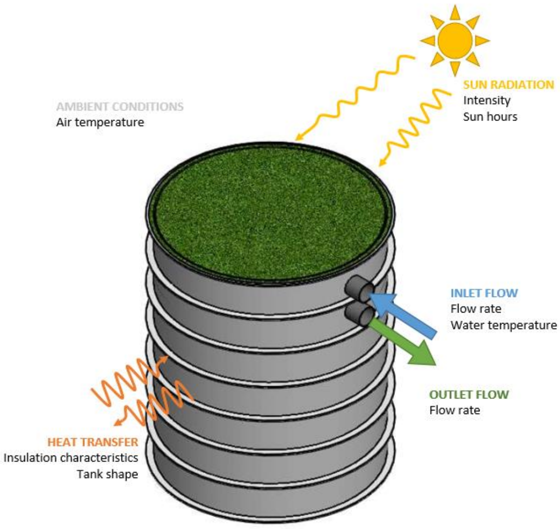

Figure 7. Schematics of Daphnia tank (over ground installation) with identified key parameters for thermal analysis simulation.

Design parameters

- Tank Installation
- Tank Insulation required
- Inlet piping insulation required

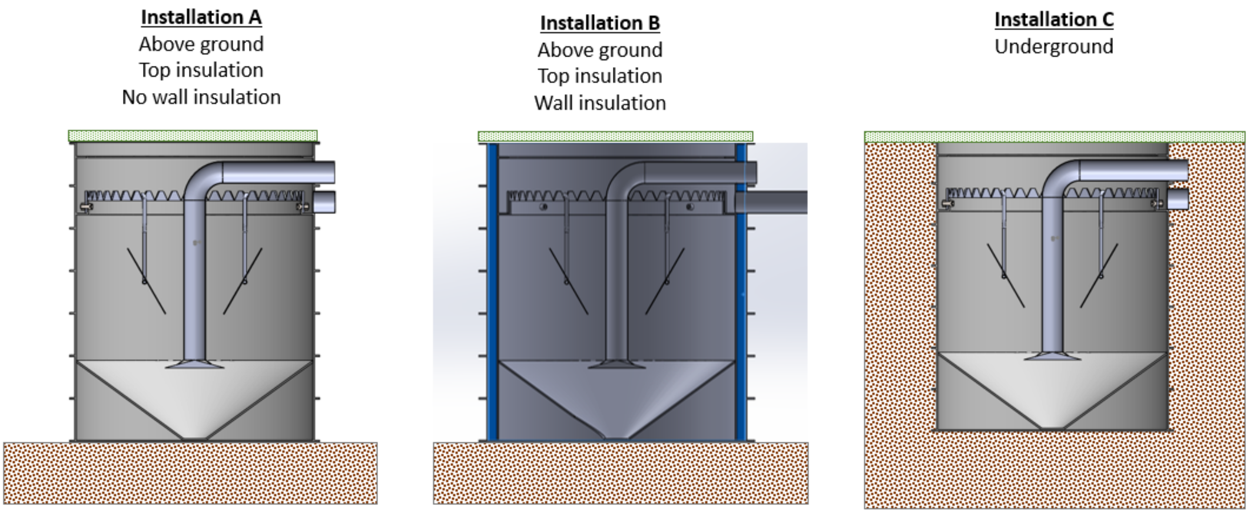

Figure 8. Daphnia tank installation options depending on the test site.

Simulation approach

An analytical approach will be followed to evaluate the suitability of the most up to date tank design considering the spectrum of test site conditions. A steady state simulation of average tank temperature will be carried out.

The outcome of this analysis will be a table defining the details of tank insulation characteristics and installation guidelines related to the main test site parameters defined above.

3.1.3.2 Lumbri tank

Design requirements

It is of the utmost importance to ensure that the daphnia tank water temperature stays within the limits defined below to ensure maximum filtering efficiency.

- Vital temperature range for Lumbri: 15-20 ºC
- Comfort temperature for Lumbri: 15-20 ºC

Design variables

The main design variables considered for the heat transfer analysis are listed below and depicted in Figure 7.

- Thermal conductivity
  - Material choices
  - Tank shape and size
- Ambient conditions: sun hours, sun radiation, air temperature (variable depending on test site)
- Inlet flow temperature (variable depending on test site)
- Inlet flow rate (variable depending on test site)

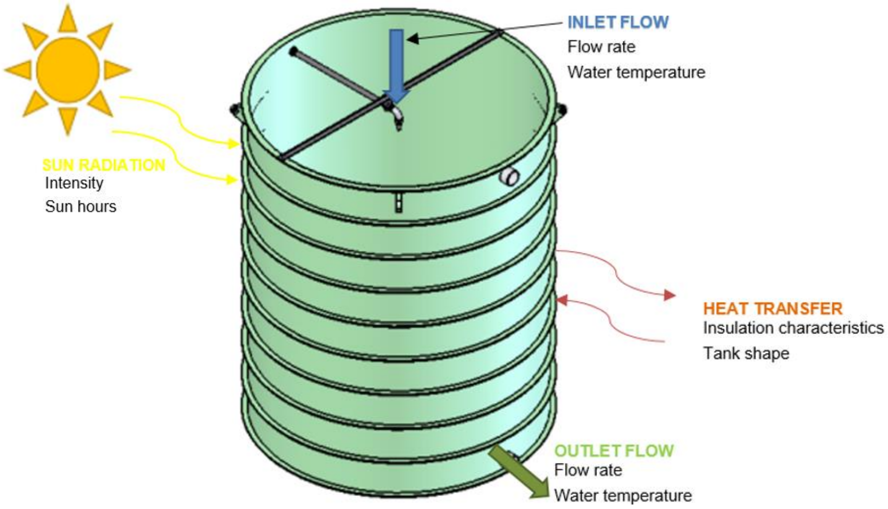

Figure 9. Schematics of Lumbri tank with identified key parameters for thermal analysis simulation.

Design parameters

- Tank Installation
- Tank Insulation required
- Inlet piping insulation required

Simulation approach

An analytical approach will be followed to evaluate the suitability of the most up to date tank design considering the spectrum of test site conditions. A steady state simulation of average tank temperature will be carried out.

The outcome of this analysis will be a table defining the details of tank insulation characteristics and installation guidelines related to the main test site parameters defined above.

3.2 Physico-Chemical and Microbiological Assessment

This section is focused on assessment the INNOQUA solution from physico-chemical and microbiological point of view. This evaluation is carried out by performing experiments under controlled conditions that assess the response of the individual INNOQUA technologies systems to each other and to various real life scenarios representative of the target markets. The major part of these evaluations will be performed throughout the WP4 (controlled scenarios) where the INNOQUA system will be evaluated under real operation conditions. Other experiments will be performed during WP2 in order to find out the points and parameters that are the most relevant in the design of the INNOQUA system, such as the compatibility of the outflowing water of the lumbrifilter with the daphnia filter and the biological compatibility of the materials.

Below, the figure presents these experimentations and its scope.

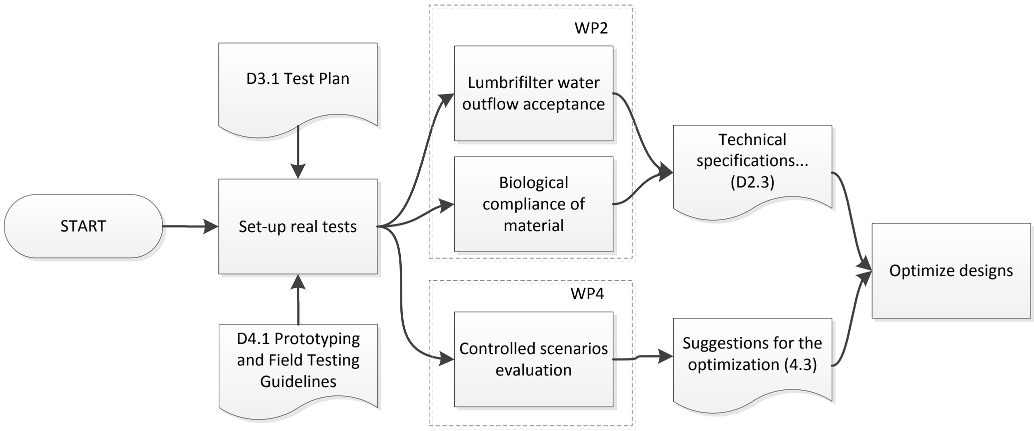

Figure 10: Physico-chemical and microbiological assessment process

As it is described in the previous figure, the evaluation process is based on three assessments: *(i)* compatibility of Lumbrifilter outflow by the Daphnia filter (see Section 3.2.1); *(ii)* biological compliance of the tanks material (see Section 3.2.2); and *(iii)* evaluation under controlled scenarios (see 3.2.3). Below, each assessment is depicted briefly. In order to achieve a more accurate description, see the future deliverables D2.3 "*Technical Specifications report including design and engineering requirements for each market target*" and D4.1 "*Prototyping and Field Testing Guidelines*".

3.2.1 Compatibility of the Lumbrifilter Water Outflow with the Daphniafilter

The aim of this test is to analyse the compatibility between lumbrifilter and daphniafilter. As it is described in the D2.1 "*Effluent physico-chemical and microbiological specifications*", initially the lumbrifilter is considered a sanitation treatment previous to the daphniafilter. Therefore, its outflow feeds the daphniafilter. The lumbrifilter sanitation process modifies the physico-chemical and bacteriological characteristics of the water (e.g. decreasing chemical oxygen demand (COD), total suspended solids (TSS)) and hence, an evaluation of how the performance of the system and the daphnia population are affected by the lumbrifilter outflow water, will be done before deciding the final design of the system and, how the two technologies will be connected.

The assessment process (see Figure 11) will be based on: *(i)* feeding the daphniafilter technology with wastewater outflowed by the lumbrifilter or with similar characteristics; *(ii)* monitoring the daphnia concentrations; *(iii)* visual inspection of the daphniafilter including particles deposition at the bottom of the tank, filaments algae growth and presence of lemna, larvae mosquitos and worms in the daphniafilter; *(iv)* monitoring the quality of the outflow water; and *(v)* analysing the influence of the inflow water (outflowing from lumbrifilter) into the daphnia filter and focusing this analysis in the impact on the daphnia population and in the purification performance.

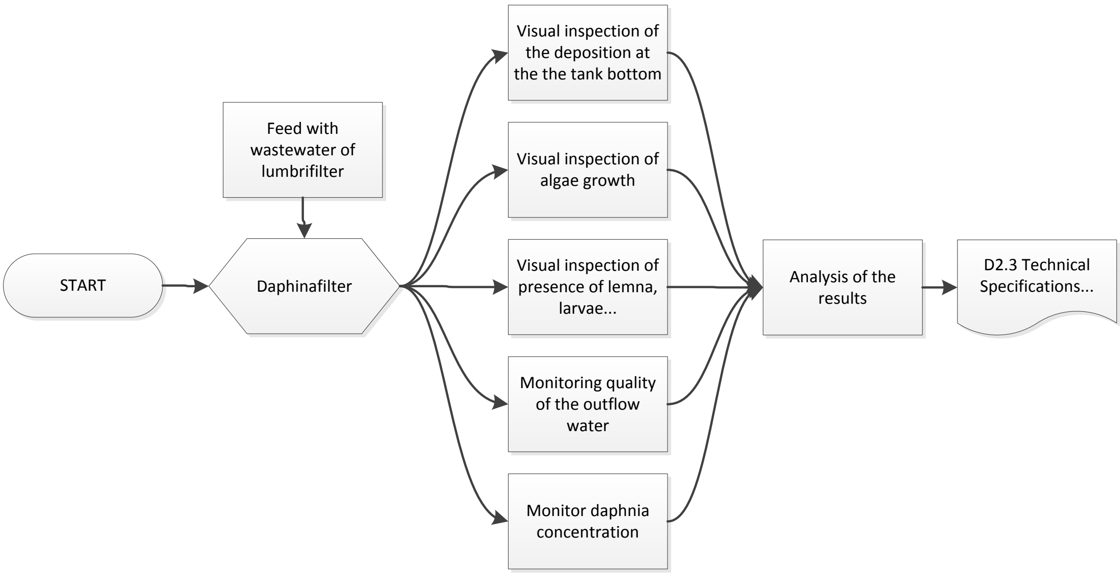

Figure 11: Lumbrifilter impact evaluation process

3.2.2 Biological Compatibility of the Lumbrifilter Water Outflow with the Daphniafilter

The aim of this test is to analyse the compatibility of the living organisms of the Daphniafilter, Daphnia, with various material options for the tanks. Therefore, the test is focused on checking the behaviour of the living organisms with the different materials by analysing of the algae growth on the materials. The assessment process (see Figure 12) will be based on: *(i)* adding different candidate material sheets inside the daphniafilter technology; *(ii)* monitoring the daphnia concentrations and *(iii)* visual inspection of the material sheets including filaments algae growth and presence of lemna, larvae mosquitos and worms in the daphniafilter.

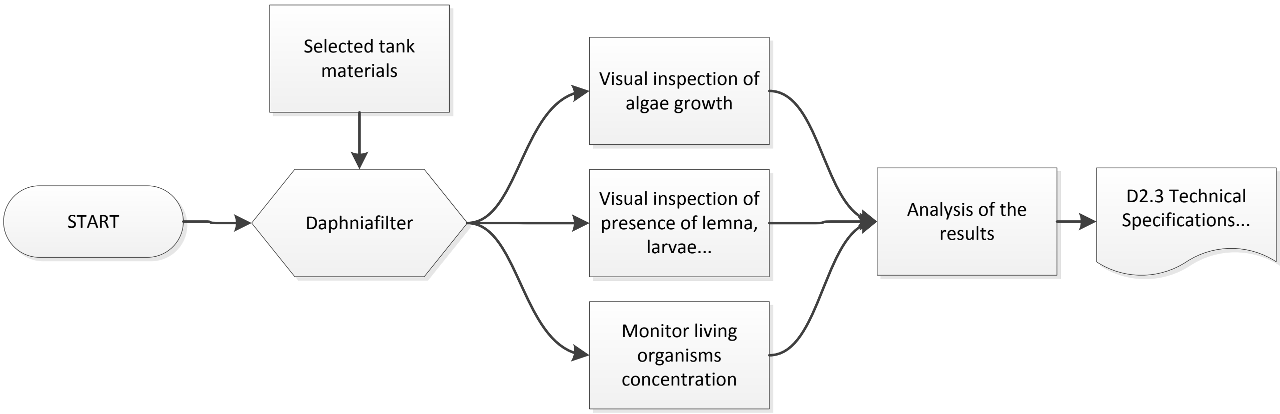

Figure 12 Biological impact evaluation of the tank material

3.2.3 Controlled Scenarios Assessment

As it was commented previously, the major part of the physico-chemical and micro-biological simulations will be performed throughout the WP4 in a controlled environment.

Mainly, these assessments will be focused on studying the impact and adaptation of the INNOQUA technologies to: *(i)* heterogeneous conditions of the pilots; *(ii)* the inflow wastewater variation (e.g. seasonal, physico-chemical characteristics including micro-contaminants, …); *(iii)* poor maintenance; *(iv)* shutdown periods and *(v)* the microbiological contamination (E. Coli, Sulphite-reducing clostridia, faecal streptococci, nematodes eggs, etc.) of the water.

The description of these tests will be presented on D4.1 "*Prototyping and Field Testing Guidelines*" (M18) and their results will be collected on D4.2 "*Prototyping and Small-Scale Field Final Report*" (M32). In D2.1, a number of key physical, chemical and microbial parameters have been identified and it is the assessment of these that will be necessary to assess and validate the performance of the prototype systems. Automated testing is not viable for all parameters and for many of those for which automation is available, routine manual validation is recommended. Where automation of parameter testing, i.e. by suitable inline test sensors, of testing is not feasible physical samples must be collected for laboratory analysis. In certain cases, where inline automated sensors are available however cost of installing such equipment and associated telemetry may be prohibitive, a mobile system such as a hand probe may be a good alternative.

For the initial prototype systems it is likely that testing of parameters will be required at inflow and outflow points in addition to in-process control testing. Table 2 lists likely inflow and outflow test points, these will vary depending on the system set-up.

Table 2: Preliminary Test Points

Test Point Ref	Test Points – Inflow/Outflow	
	Upstream of	Downstream of
1	Primary Treatment	Inflow to System
2	Lumbrifilter	Primary Treatment
3	Daphniafilter	Lumbrifilter
4	BSP	Daphniafilter
5	Outfall	BSP
6	UV Pulse	Lumbrifilter
7	Outfall	UV Pulse
9	UV Pulse	Lumbrifilter

An initial list of key physical, chemical and microbial parameters is given in Table 3 following along with a list of suitable test apparatus for its assessment.

Table 3: Preliminary Test Schedule

Parameter	**Units**			**Suitable Test Apparatus**		
		Inflow/ Outflow	**In-Process**	**Auto/Fixed Inline Sensor**	**Mobile Sensor Hand Probe**	**Grab Sample/Lab Testing**
Flow	m^3	✓	✓	✓	x	x
Temp	^oC	✓	✓	✓	✓	x
Suspended Solids	mg/L	✓	✓	✓	✓	✓
Turbidity	NTU	✓	✓	x	x	✓
pH		✓	✓	✓	✓	✓
BOD	mg/L	✓	✓	x	x	✓
BOD5	mg/L	✓	✓	x	x	✓

COD	mg/L	✓	✓	✓	x	✓
Ammonium (NH_4^+)	mg/L	✓	✓	✓	x	✓
Ammonia (NH_3^+)	mg/L	✓	✓	x	x	✓
Dissolved oxygen (O_2)	mg/L	✓	✓	✓	✓	✓
Total Nitrogen	mg/L	✓	✓	✓	✓	✓
Nitrate	mg/L	✓	✓	✓	✓	✓
Total Phosphate (P)	mg/L	✓	✓	✓	✓	✓
Total Orthophosphate (PO_4)	mg/L	✓	x	✓	✓	✓
Escherichia coli	(cfu/L)	✓	x	x	x	✓
Faecal enterococci	(cfu/L)	✓	x	x	x	✓
Total coliforms	(cfu/L)	✓	x	x	x	✓
Legionella sp	(cfu/L)	✓	x	x	x	✓
Salmonella sp	(cfu/L)	✓	x	x	x	✓
Norovirus	(cfu/L)	✓	x	x	x	✓
Enterococci	(cfu/L)	✓	x	x	x	✓
Cryptosporidium	(cfu/L)	✓	x	x	x	✓

3.3 ICT Assessment

The objective of ICT assessment is focused on evaluating the Monitoring and Control Unit (MCU) determining and validating the speed, scalability, and stability characteristics of the ICT components in order to assure that they meet both technical specifications and requirements (see D2.2 *"Engineering and Structural Specifications including monitoring requirements and specifications"*).

Annex A (see Section 7) provides a brief introduction to the ICT components, a complete and final description is planned on D2.2 (M12). This conceptualization of the ICT components enables the reader to understand the different tests to be performed.

Below, the ICT assessment process for these components is presented in the Figure 13.

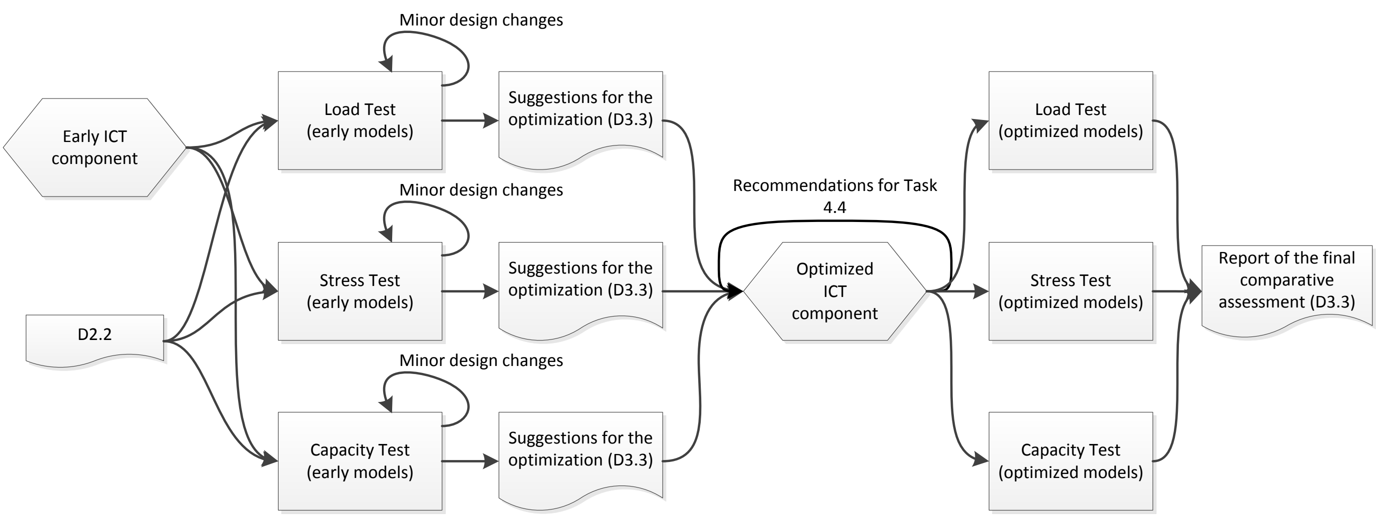

Figure 13: ICT assessment process

The assessment of the ICT components (Data Sampling, Gateway and Monitoring and Control Platform) will be focused on: *(i)* load tests (LT) to verify the behaviour under normal and peak load conditions; *(ii)* stress tests (ST) to validate the behaviour when it is pushed beyond normal or peak load conditions; and *(iii)* capacity test (CT) to determine the limits of the component (e.g. how many user and/or transactions a given system will support and still meet performance goals).

Each test type is motivated to evaluate different situations or states of the ICT components, therefore their benefits for INNOQUA project are not the same. For instance, the verification of the behaviour under normal conditions (LT) allows to: *(i)* determine the throughput required to support the anticipated peak production load; *(ii)* determine the adequacy of the hardware and software environment; *(iii)* evaluate the adequacy of a load balancer; *(iv)* detect concurrency issues; *(v)* detect functionality errors under load; *(vi)* collect data for scalability and capacity-planning purposes; *(vii)* help to determine how many users/devices the application can handle before performance is compromised; and *(viii)* help to determine how much load the hardware can handle before resource utilisation limits are exceeded.

The stress test evaluates the behaviour of the ICT components beyond peak load conditions, it can provide the following benefits: *(i)* determine if data can be corrupted by overstressing the system; *(ii)* provide an estimate of how far beyond the ICT component target load can go before causing failures and errors in addition to slowness; *(iii)* establish application-monitoring triggers to warn of impending failures; *(iv)* ensure that security vulnerabilities are not opened up by stressful conditions; *(vi)* determine the side effects of common hardware or supporting application failures; and *(viii)* help to determine what kinds of failures are most valuable.

Capacity tests: *(i)* provide information about how workload can be handled to meet business requirements; *(ii)* provide actual data that can be used to validate or enhance the ICT module; *(iii)* conduct various tests to compare the performance of the solution; *(iv)* determine the current usage and capacity of the existing system to aid in capacity planning; and *(v)* provide the usage and capacity trends of the existing system to aid in capacity planning.

The test set designed is made up of eleven tests, 4 of which are load tests (LT), 3 of which are stress tests (ST), and 3 of which are capacity tests (CT). A brief description of each test is offered in Table 4.

Table 4: Summary and description of the ICT tests

Test identifier	Type (LT/ST/CT)	Title	Description
T1	LT	"Data sampling" component under normal conditions.	Evaluate the throughput and behavior of the "Data Sampling" component when collects samplings on normal conditions.
T2	LT	"Gateway" component under normal conditions.	Evaluate the throughput and behaviour of the "Gateway" component when manages the data generated by the "Data Sampling" components on normal conditions.
T3	LT	"Monitoring and control" platform under normal conditions.	Evaluate the throughput and behaviour of the "Monitoring and Control" platform when is accessed by the users on normal conditions.
T4	LT	"Data Sampling" and "Gateway" communication	Determine the broadcast power used by the "Gateway" and "Data Sampling" components to ensure the communication in base to the INNOQUA dimensions.
T5	ST	"Data sampling" component beyond normal conditions	Evaluate the behaviour of the "Data Sampling" component working with sampling frequencies above normal conditions.
T6	ST	"Gateway" component beyond normal conditions	Evaluate the behaviour of the "Gateway" component when collect data from a number of "Data Sampling" components that exceeds the expected.
T7	ST	"Monitoring and control" platform beyond normal conditions	Evaluate the behaviour of the "Monitoring and Control" platform working with a number of users that exceeds the expected.
T8	CT	Maximum and stable performance assessment of the "Data sampling" component.	Determine the maximum sampling frequency for the "Data Sampling" components.
T9	CT	Maximum and stable performance assessment of the "Gateway" component.	Determine the maximum number of "Data Sampling" components feeding the "Gateway" component.
T10	CT	Maximum number of users and stable performance assessment of the "monitoring and control" platform.	Determine the maximum number of concurrent users supported by the "Monitoring and Control Unit" platform

Below, each test presented above is introduced reviewing its objectives, the benefits it provides and the process to be followed. Moreover, it is important to note that in the major part of the tests, the memory and CPU consumption will be probably affected during the testing process by the profiling but it will be disregarded.

3.3.1 T1 - "Data Sampling" component under normal conditions

In the INNOQUA IoT architecture, the "*Data Sampling*" component is responsible for collecting the measurements and broadcast them to the "*Gateway*" component as it is depicted in the Section 3.3. This test is aimed to evaluate the throughput and behaviour of the "*Data Sampling*" component during peak of measurement load in order to: *(i)* determine the adequacy of the "Data Sampling" component, that is, conclude if the hardware and software have been properly sized for the requirements defined on D2.2; *(ii)* detect concurrency issues and errors produced by the high workload such as delays in measurements, missing or corrupt measures, unexpected crashes…; and *(iii)* determine improvements due to the understanding of the errors identified during the test (for instance, optimize the access to the sensors…).

The test will be based on empirical procedure that consists of four steps: *(i)* configure the "*Data sampling*" component to work with the expected number of sensors and their corresponding sampling rate (use the hardest pilot configuration, that is, the pilot with the maximum number of sensors and the most highest frequency rate – see D2.2); *(ii)* monitor the memory consumption during the test; *(iii)* monitor the measured data, type of observation and the instant of each measurement throughout a reasonable period of time (the period should be defined based on frequency sampling – see D2.2); and *(iv)* take advantage of the stored information (memory consumption, phenomenon, time and monitored data) to analyse the component behaviour on normal conditions focusing in the appearance of corrupt measurements, a sampling rate lower than the defined or an irregular pattern of memory consumption.

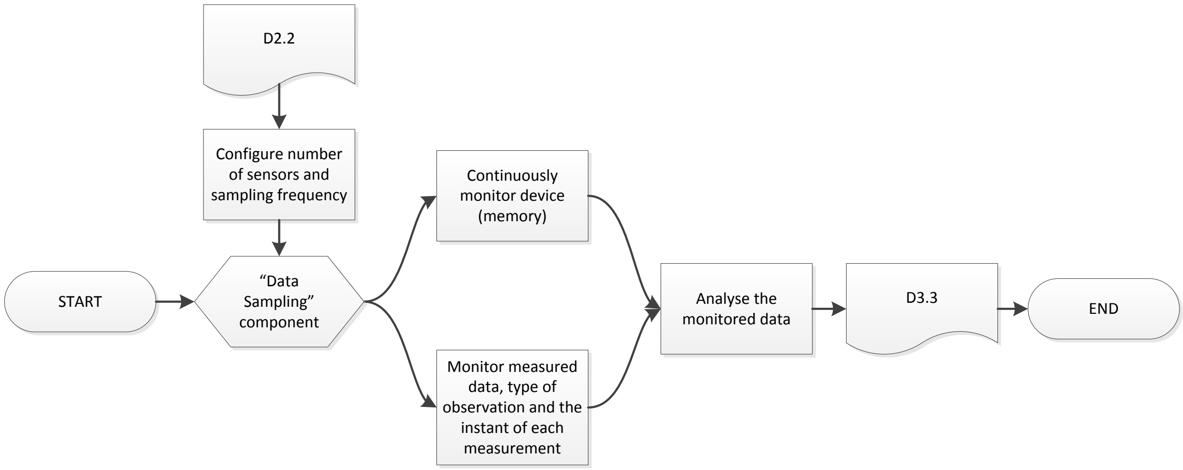

Figure 14: Assessment procedure for T1 - "Data Sampling" component under normal conditions procedure

3.3.2 T2 - "Gateway" component under normal conditions

The second test is similar to the first test, but the assessment is focused in the "*Gateway*" component. The "*Gateway*" component is the responsible for collecting the information measured by the "*Data Sampling*" components, transform it and store it to be exploited by the "*Monitoring and Control*" platform.

The aim of this test is evaluate the "*Gateway*" component under normal conditions to: *(i)* determine if the hardware and software have been properly sized for the requirements defined on D2.2 and hence it is able to manage all measurements provided by the "*Data Sampling*" components; *(ii)* detect concurrency issues such as bottlenecks on communication, data processing or data persistence; and *(iii)* determine improvements due to the understanding of the errors identified during the test (for instance, improve the data persistence by using or configuring connection pools, optimize code to data processing, …).

The test will be also based on empirical procedure that consists of four steps: *(i)* simulate the communication (e.g. MQTT messages or CoaP queries) from "*Data sampling*" components to "*Gateway*" component by using testing tools such as Apache JMeter[1] or the like reproducing the toughest case with multiple "*Data sampling*" components that monitor several phenomenon – see D2.2; *(ii)* monitor and store the CPU and memory consumption during the test; *(iii)* monitor the transaction and storage time for each measurement received throughout a reasonable period of time (the period should be defined based on frequency sampling – see D2.2); and *(iv)* take advantage of the stored information to analyse the "*Gateway*" component behaviour on normal conditions focusing on discover irregular patterns of CPU or memory consumption and transaction/storage time that shows the system slowdown.

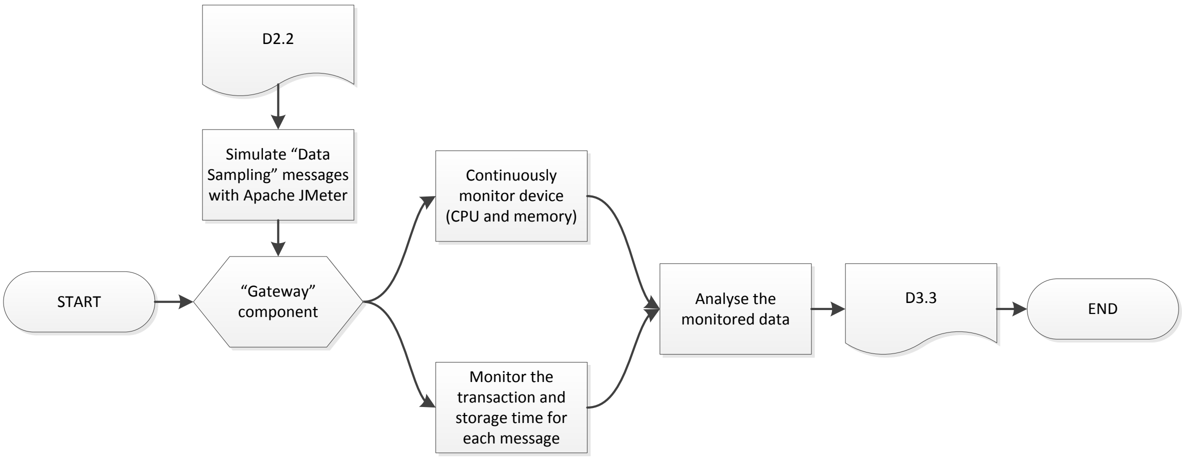

Figure 15: Assessment procedure for T2 - "Gateway" component under normal conditions procedure

3.3.3 T3 - "Monitor and Control" platform under normal conditions

The third load test is focused on *"Monitoring and Control"* platform and its aim is to evaluate the throughput of this component when it is operated on normal conditions by simulating of the concurrent end-user interaction with the platform. The end-user interaction will be simulated through SOAP or REST queries by using testing tools such as Apache JMeter or the like. Moreover, these simulated end-users will perform everyday actions on the platform as can be: see the evolution of the daphnia tank temperature, ammonia concentration in the lumbrifilter outflow, see the past alerts, …

Basically, this test is based in four steps which are: *(i)* simulate the end-user interactions taking advantage of the requirements depicted in D2.2 "*Engineering and Structural Specifications (including monitoring requirements and specifications)*" to define the concurrent number of end-users and the daily operations; *(ii)* monitor the CPU and memory consumption of the platform container (e.g. Apache Tomcat[2]) throughout the test; *(iii)* monitor the response time and the accuracy for each request; and *(iv)* take advantage of the stored information (CPU and memory consumption, request time and accuracy) to analyse the "*Monitor and Control"* behaviour on normal conditions focusing on

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[1] Official page http://jmeter.apache.org/

[2] Official page http://tomcat.apache.org/

discover irregular patterns of CPU or memory consumption of the platform container, excessive action times that shows the system slowdown and non-valid execution of actions.

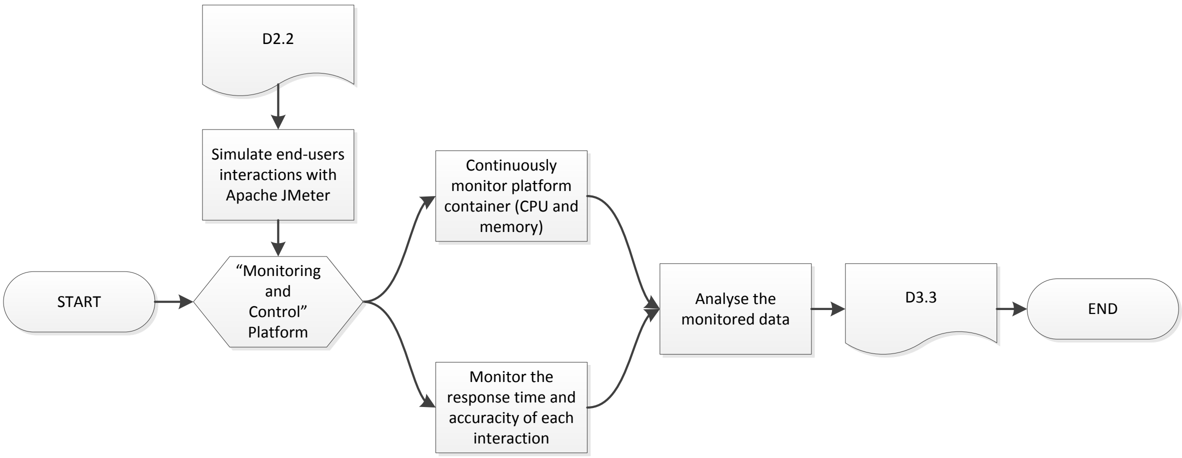

Figure 16: Assessment procedure for T3 - "Monitor and Control" platform under normal conditions procedure

Finally, the analysis performed in step *(iv)* will be focused on: *(i)* determining if the platform is prepared to support the interactions of the users defined on D2.2 "*Engineering and Structural Specifications (including monitoring requirements and specifications)*"; *(ii)* detecting possible issues such as bottlenecks on platform interfaces, data processing or data access; *(iii)* determining improvements due to the understanding of the errors identified during the test (for instance, improve the data access by using or configuring connection pools, optimize code to data processing, …).

3.3.4 T4 - "Data Sampling" and "Gateway" communication

The T1 and T2 assess the capacity of "*Data Sampling*" and "*Gateway*" component under normal conditions separately, these assessments allow to ensure that both components are ready to measure and send the data and capture and persist them respectively. Therefore, if they are able to manage the expected rate separately, they should be able to work together with the expected rate. Nonetheless, the use of wireless technologies in the communication between components poses a new test scenario. The wireless communication range depends of two factors, one is given by the limits of the technology used and another is conditioned by the transmission power. A higher transmission power provides a greater range, instead the consumption is higher too. Then, it is important to adjust the transmission power to INNOQUA design avoiding unnecessary energy consumption.

This test will be performed by an empirical test with the ICT components that will be based on four steps: *(i)* collect the distance requirements for the INNOQUA components from D2.2 *"Engineering and structural specifications (including monitoring requirements and specifications)"*; *(ii)* configure ITC INNOQUA components to work on the minimum power; *(iii)* assess whether the components are able to communicate with each other on the defined distance (see step *(i)*); *(iv)* increase the transmission power and repeat the step *(iii)* until they can communicate. Once the components are able to establish the communication, the transmission power defined is the minimum transmission power to work by the INNOQUA components.

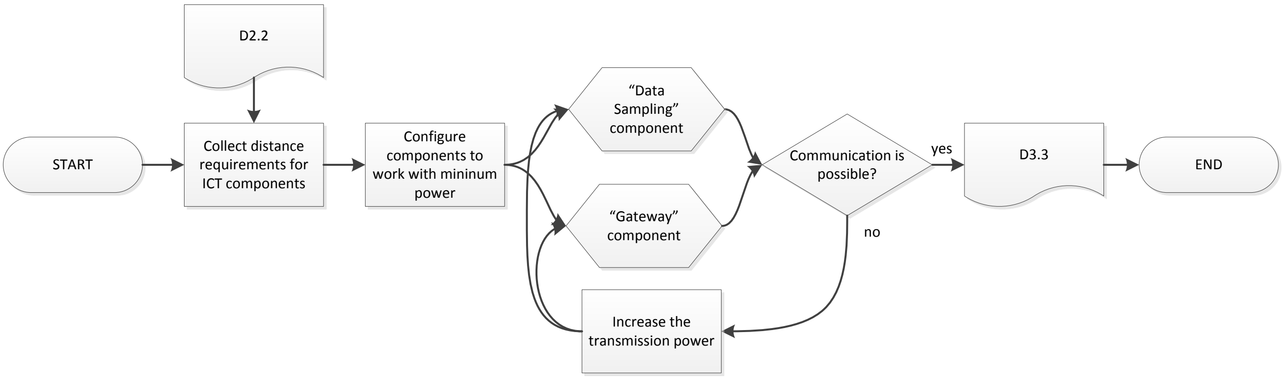

Figure 17: Assessment procedure for T4 - "Data Sampling" and "Gateway" communication

Summarising, the outcomes of this test will be used to: *(i)* determine the minimum transmission power of the monitoring INNOQUA components to establish the communication; and *(ii)* minimize the consumption of the INNOQUA components.

3.3.5 T5 - "Data sampling" component beyond normal conditions

This test is the first of the stress test and it is focused on *"Data sampling"* component. Mainly, it aims at validating the behaviour of the "Data sampling" component when it is pushed beyond normal or peak load conditions, that is, evaluate its behaviour when it works with a greater number of sensors and a higher sampling ratio than expected.

It will be also based on empirical procedure that consists of four steps: *(i)* configure the *"Data sampling"* component to work with a greater number of sensors than expected (e.g. an increase of twenty percent) and a sampling rate higher (e.g. also an increase of twenty percent); *(ii)* monitor the memory consumption during the test; *(iii)* monitor the measured data together with type of observation and the instant of each measurement throughout a reasonable period of time (the period should be defined based on frequency sampling – see D2.2); and *(iv)* take advantage of the stored information (memory consumption, type of observation, time and monitored data) to analyse the component behaviour on stress conditions focusing in the appearance of corrupt measurements, suitable sampling rate and memory consumption within reasonable limits.

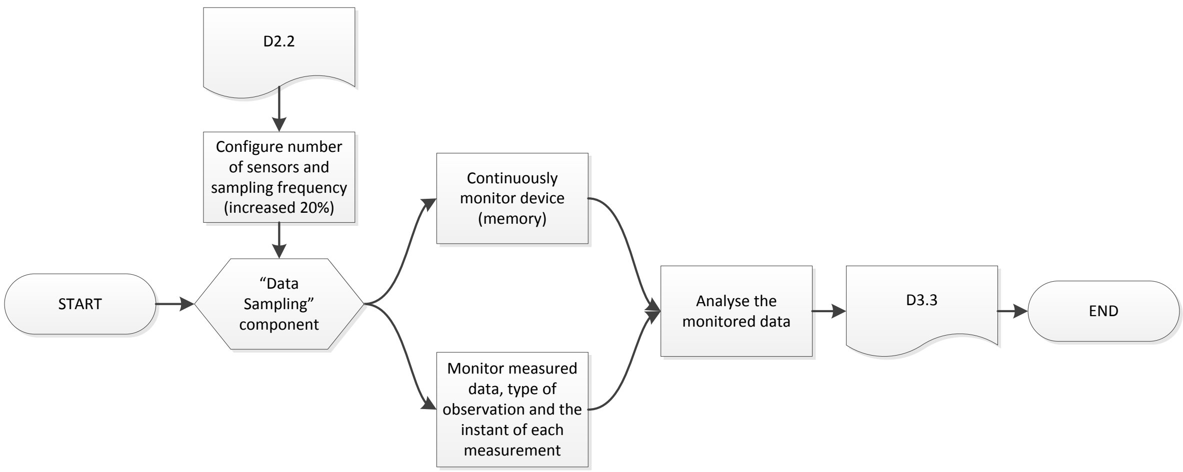

Figure 18: Assessment procedure for T5 - "Data Sampling" component beyond normal conditions

Summarising, this analysis will be focused on: *(i)* determining if the overstressing of the *"Data Sampling"* component corrupts the measures collected (e.g. non-value measures; invalid measures…) and *(ii)* determining if *"Data Sampling"* component is able to work on stress conditions without slow down it (e.g. outdated measures by a sampling rate lower).

3.3.6 T6- "Gateway" component beyond normal conditions

The T6 aims at validating the behaviour of the *"Gateway"* component when it is pushed beyond normal or peak load conditions. Therefore, this test will assess its behaviour on stress situations, that is, when the "Gateway" component works with a greater number of sensors than expected and sampling rates higher.

Mainly, the test will be based on an empirical evaluation that consists of four steps: *(i)* simulate the communication (e.g. MQTT messages or CoaP queries) from *"Data sampling"* components to *"Gateway"* component by using testing tools such as Apache JMeter[3] or the like to reproduce fictitious communication peaks (e.g. an increase of twenty percent in the number of sensors and the frequency sampling) *(ii)* monitor and store the CPU and memory consumption during the test; *(iii)* monitor the transaction time and storage time for each simulated communication received; and *(iii)* take advantage of the stored information to analyse the "Gateway" component behaviour on conditions beyond normality focusing in the data loss and abnormal patterns of CPU and memory consumption.

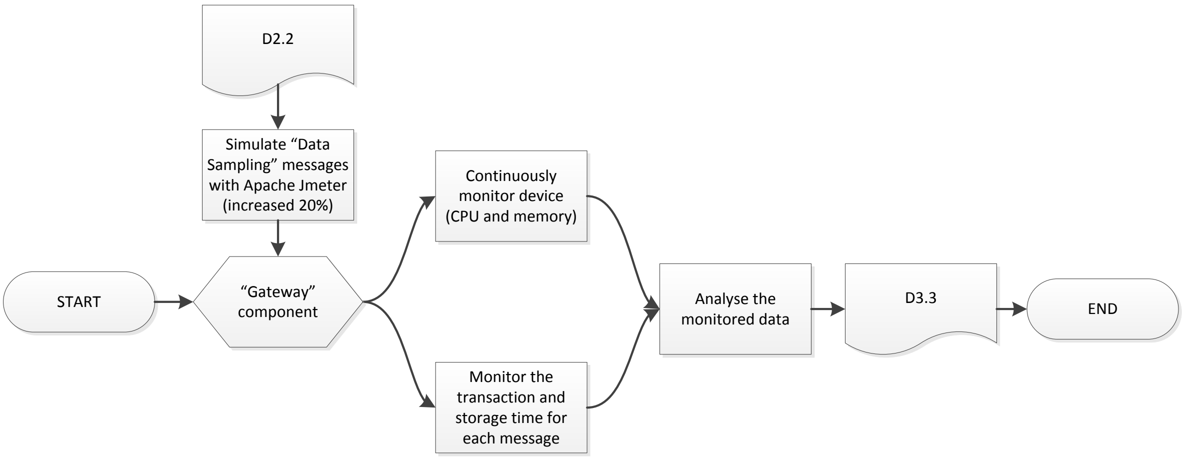

Figure 19: Assessment procedure for T6 - "Gateway" component beyond normal conditions

Finally, the analysis will be focused on: *(i)* determining if the overstressing of the "Gateway" component loses data which are not stored in the internal database; and *(ii)* determining if the "Gateway" component is able to work on stress conditions without slowing down.

[3] Official page http://jmeter.apache.org/

3.3.7 T7- “Monitoring and Control” platform beyond normal conditions

The T7 is addressed to validate the behaviour and throughput of the *“Monitoring and Control Unit”* platform beyond normal conditions by simulating multiple concurrent users accessing the platform. These simulated users will perform everyday actions on the platform eg: view the evolution of the daphnia tank temperature, see the past alerts etc. but with a number of users that exceeds the expected.

As with the previous test, this test is also based in four steps which are: *(i)* simulate the user interactions by using testing tools such as Apache JMeter[4] or the like (the definition of the concurrent number of users and daily operation will be based on the D2.2 requirements which will be expanded a 20% to simulate the peak); *(ii)* monitor the CPU and memory consumption of the platform container (e.g. Apache Tomcat[5]) throughout the test; *(iii)* monitor the time required to attend each request; and *(iv)* take advantage of the stored information (CPU and memory consumption, request time) to analyse the component behaviour on beyond normal conditions focusing on abnormal patterns of the CPU and memory consumption and excessive time to attend requests.

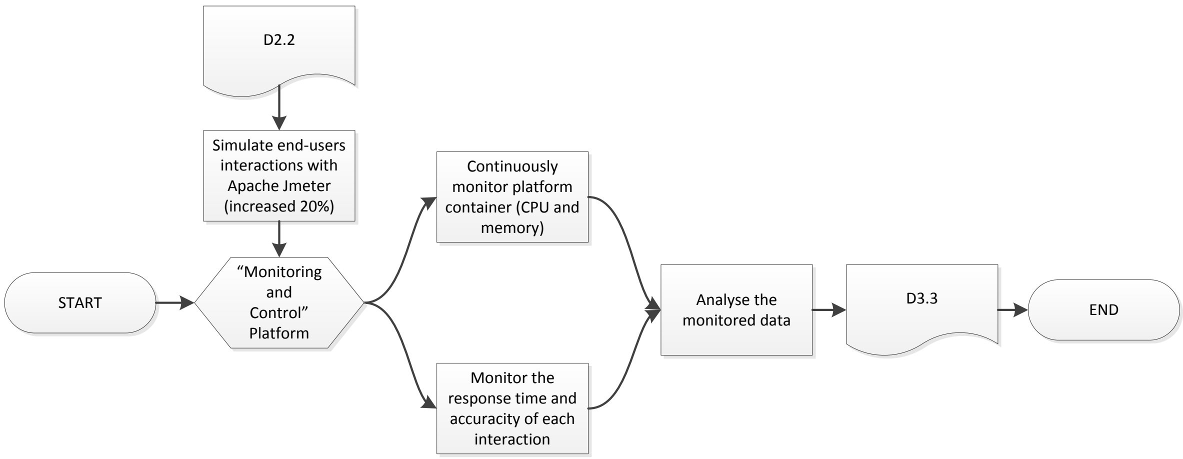

Figure 20: Assessment procedure for T7 - “Monitoring and Control” platform beyond normal conditions

Basically, the analysis performed in the step *(iv)* will be focused on: *(i)* determining if the platform is prepared to support a more intense use than previously planned on D2.2; *(ii)* detecting possible issues such as bottlenecks on platform interfaces, data processing or data access; *(iii)* determining improvements due to the understanding of the errors identified during the test (for instance, improve the data access by using or configuring connection pools, optimise code to data processing, …).

[4] Official page http://jmeter.apache.org/

[5] Official page http://tomcat.apache.org/

3.3.8 T8 – Maximum and stable performance assessment of the "Data sampling" component

The "Data sampling" component has two key elements which are: *(i)* number of sensors and *(ii)* the sensor logging frequency. The number maximum of sensors is basically limited by the hardware design and hence it is not easily expandable. Instead, the sensor logging frequency is a configurable parameter that can be increased. Therefore, the T8 is aimed to discover the limit of sensor logging frequency for the *"Data Sampling"* component by increasing the sampling ratio until to reach the maximum and stable value.

The test will be based in four steps which are: *(i)* configure the "Data Sampling" component to work with the maximum number of sensors and their expected sensor logging frequency; *(ii)* monitor the memory consumption, measured data, type of observation and the instant of each measurement throughout a reasonable period of time (the period should be defined based on frequency sampling – see D2.2); *(iii)* if the *"Data Sampling"* component supports this configuration (non-appearance of corrupt measurements, acceptable sampling rate and normal memory consumption), come back to step *(i)* increasing the sensor logging frequency, if not follow to next step; *(iv)* collect the results of the assessment in the D3.3.

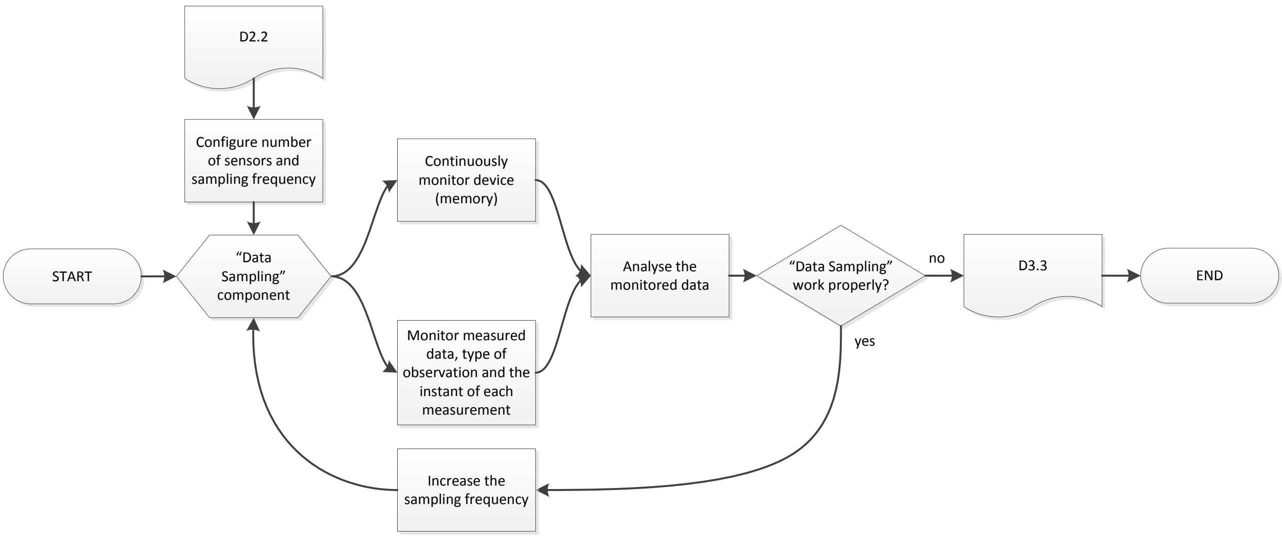

Figure 21: Assessment procedure for T8 - Maximum and stable performance assessment of the "Data sampling" component

Basically, the analysis performed in the step *(iv)* allow to: *(i)* determine the maximum frequency supported by the "Data Sampling" component working with the maximum number of sensors and *(ii)* detect bottlenecks on microcontroller codification.

3.3.9 T9 - Maximum and stable performance assessment of the "Gateway" component

The "*Gateway*" component centralised all the data coming from the "*Data Sampling*" components, hence it is important to know how many "*Data Sampling*" components are able to manage without compromising its integrity. Then, the T9 is basically addressed to discover this limit thanks to the incremental simulation of the integrated "*Data Sampling*" components in the "*Gateway*" component. The simulated "Data Sampling" components will be characterized with three sensors using the start-up sampling frequency defined in the D2.2.

The steps of this test can be summarised as follows: *(i)* simulate the communication (e.g. MQTT messages or CoaP queries) from "*Data Sampling*" components to "*Gateway*" component by using testing tools such as Apache JMeter[6] or the like; *(ii)* monitor the CPU and memory consumption, transaction time and storage time of the "*Gateway*" component throughout a reasonable period of time (the period should be defined based on frequency sampling – see D2.2); *(iii)* if the "*Gateway*" component is able to manage the gathered data (normal CPU and memory consumption patterns and no-loss of data), come back to step *(i)* adding a new simulated "*Data Sampling*" component, if not follow to next step; *(iv)* collect the results of the assessment in the D3.3.

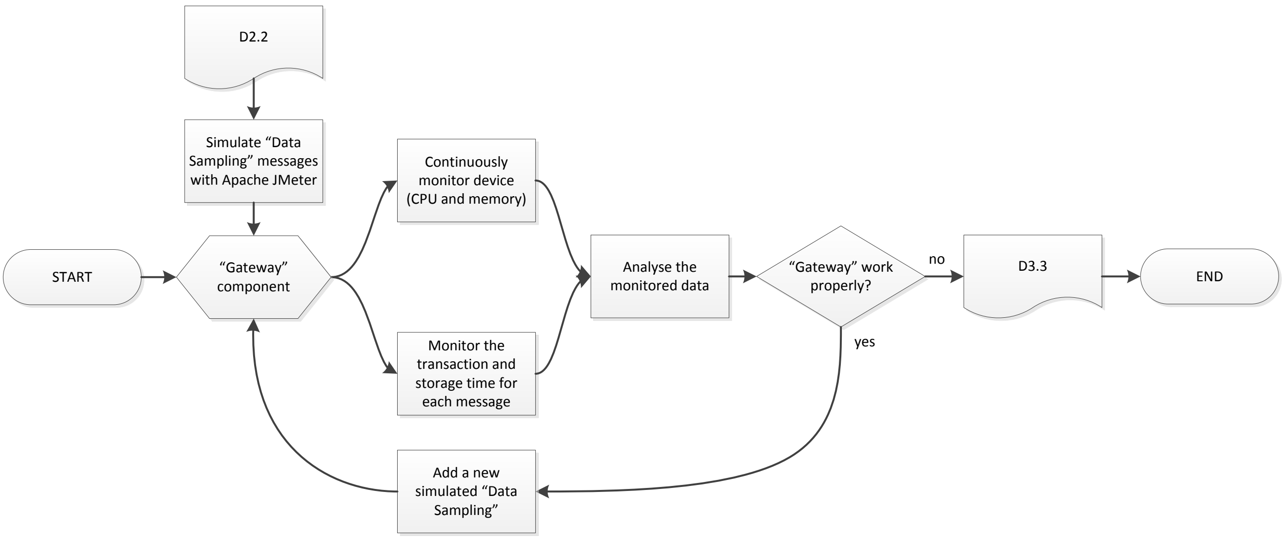

Figure 22: Assessment procedure for T9 - Maximum and stable performance assessment of the "Gateway" component

Basically, test allows to: *(i)* determine the maximum number of "*Data Sampling*" components feeding the "*Gateway*" component; *(ii)* detect bottlenecks on microcontroller codification by a mismanagement of the incoming communications or connection pool; and *(iii)* determine improvements to the "*Gateway*" component by the understanding of the impact of an incremental number of "*Data Sampling*" components.

3.3.10 T10 - Maximum number of users and stable performance assessment of the "Monitoring and Control Unit" platform

As it was described upon (see Section 3.3), the "Monitoring and Control Unit" platform is the interface to the INNOQUA users with ICT system. Then, the capacity test of the "Monitoring and Control Unit" is addressed to determine the maximum number of concurrent users supported by the platform.

[6] Official page http://jmeter.apache.org/

The steps of this test are: *(i)* simulate the interaction of a user with the platform through the calls to the web services operations (REST or SOAP calls depending of the final implementation of the platform) of the platform by using testing tools (e.g. Apache JMeter or the like); *(ii)* monitor the CPU and memory consumption of the platform container (e.g. Apache Tomcat[7]) throughout the test; *(iii)* monitor the operation time required for each request; *(iv)* monitor the accuracy of the response, that is, if the response is the expected or not and; *(v)* if the platform is able to manage the simulated users (normal CPU and memory consumption patterns, acceptable response times and valid responses), go to step *(i)* adding a new simulated user, if not follow to next step; *(v)* collect the results of the assessment in the D3.3.

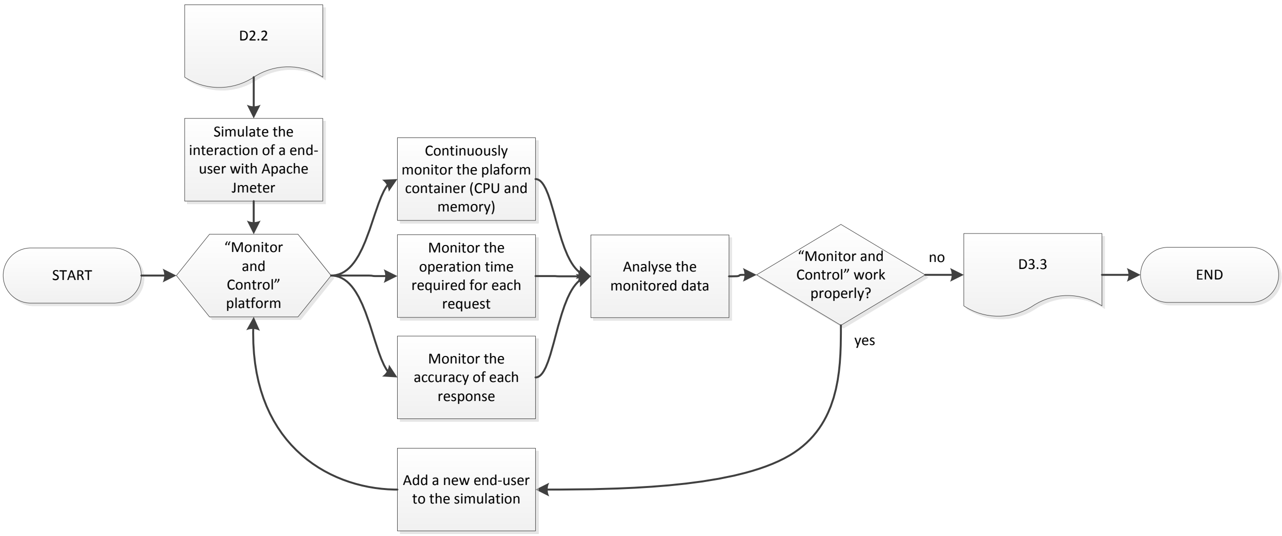

Figure 23: Assessment procedure for Maximum number of users and stable performance assessment of the "Monitoring and Control Unit" platform

Basically, the test performed allows to: *(i)* determine the maximum number of concurrent users to the "*Monitoring and Control Unit*" platform; *(ii)* detect bottlenecks on microcontroller codification by a mismanagement of the incoming communications or connection pool; and *(iii)* determine improvements to the "*Gateway*" component by the understanding of the impact of an incremental number of "*Data Sampling*" components.

[7] Official page http://tomcat.apache.org/

4 Environmental & Economic Evaluation

The aim of this evaluation is to minimise the environmental and economic impact of the INNOQUA solution by applying sustainable and rational design decisions which will be supported by tools such as: *(i)* Life Cycle Analysis (LCA) study; *(ii)* Life Cycle Cost (LCC) study and *(iii)* Environmental Technology Verification (ETV) program.

The LCA study will compare the full range of environmental effects assignable to INNOQUA solution by quantifying all inputs and outputs of material flows and assessing how these material flows affect the environment.

The LCC study to determine the most cost-effective option among different competing alternatives to purchase, own, operate, maintain and, finally, dispose of an object or process, when each is equally appropriate to be implemented on technical grounds.

Finally, ETV program provides access to third-party validation of the performance of innovative environmental technologies presenting an added value for the environment and ready for the market.

From the environmental point of view, the assessments will:

a) Assess whether the INNOQUA solutions perform at least as conventional sanitary systems
b) Support the design process to take informed decisions related to environmental performance
c) Demonstrate the strong points of INNOQUA technology in terms of avoided impacts
d) Prove the reliability of their credits by assessment of third parties

On the other, from an economic approach the assessments will:

a) Assess whether the INNOQUA solutions are in line with current market sanitary systems
b) Support the design process in economic terms by the identification of potential economic savings

4.1 LCA & LCC study

This section describes the process or evaluation steps to perform the LCA & LCC study on INNOQUA project. Moreover, the LCA study and LCC study are introduced defining their goals, scope and main characteristics.

4.1.1 LCA study

Life Cycle Analysis (LCA) is a tool to assess the environmental impacts and resources used throughout a product's life cycle, i.e., from raw material acquisition (cradle), via production and use phases, to waste management (grave). The LCA includes different phases: *(i) Goal and Scope*; *(ii) Inventory Analysis* (LCI); *(iii) Impact Assessment* (LCIA); and *(iv) Interpretation* of the results that provide conclusions and recommendations. These phases are defined in ISO 14040/44 standards and are summarised in Figure 24.

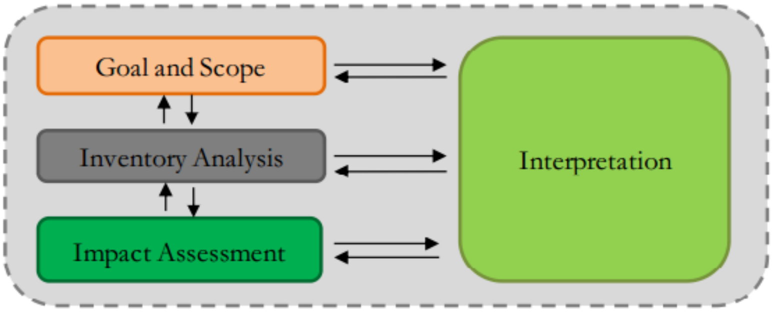

Figure 24: The phases of an LCA according to ISO 14040

Goal and scope

First, the goal and scope includes the reasons for carrying out the study, the intended application, and the intended audience. It is also the place where the system boundaries of the study are described and the functional unit (FU) is defined. The functional unit is a measure of the performance of the functional outputs of the product system. The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related[8]. The system boundaries determine which unit processes shall be included within the LCA study. For example, in INNOQUA project, the Functional Unit could be 1 m^3 of wastewater, 1 m^3 of treated water, water treatment for 1 Population Equivalent or other.

Life cycle inventory (LCI)

The life cycle inventory (LCI) is an inventory of input/output data with regard to the system being studied. It involves collection of the data necessary to meet the goals of the defined[9]. The result from the LCI is a compilation of the inputs (resources) and the outputs (emissions) from the product over its life-cycle in relation to the FU[10].

Input and output data have to be collected for each life cycle stage that is included in the system boundaries. Project partners will be requested to provide information to elaborate the life cycle inventory.

Life cycle processes include many activities, which may be split into different steps. The information is compiled for each step within the scope of the study. As a general rule, input data refers to the quantity of materials consumed and transported to the production sites (referred as input materials) and the energy and water consumption; while output data refers to the quantity of materials, waste water flows, emissions to the air and solid waste produced and transported to treatment plants. Figure 25 represents input and output flows per each step.

[8] Source: ISO 14040:2006 Environmental management -- LCA -- Principles and framework and 14044:2006 Environmental management -- LCA -- Requirements and guidelines

[9] ISO 14040/44

[10] Finnvenden et al., 2009, Recent developments in Life Cycle Assessment. Journal of Environmental Management, 91, 1-21.

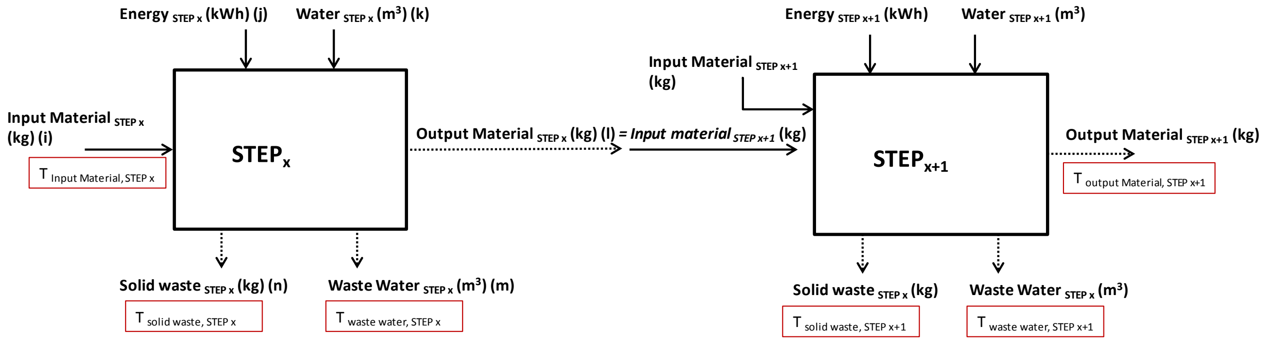

Figure 25: Input/output flow per step

Input/output data is collected from providers and afterwards is referenced to the Functional Unit.

In INNOQUA project, key parameters will be: materials used for manufacturing the treatment plant, transportation of goods, energy consumption during operation and emissions generated (solid and gaseous).

Life Cycle Impact Assessment (LCIA)

The life cycle impact assessment (LCIA) is expected to evaluate the potential environmental impacts transforming all the inputs and outputs into a few impact categories. It is aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of the studied system[11].

Different evaluation methods are available (e.g. ReCiPe method…) which will be reviewed in order to be applied on INNOQUA activities.

Life cycle interpretation

The fourth phase is the interpretation, in which the results from the previous phases are evaluated in relation to the goal and scope in order to reach conclusions and recommendations[12]. The findings of this interpretation may take the form of conclusions and recommendations to decision makers. It may also take the form of an improvement assessment, i.e. an identification of opportunities to improve the environmental performance of products or processes.

4.1.2 LCC study

The aim of Life Cycle Cost (LCC) analysis is to take into account all the costs that will be incurred during the lifetime of a product or service (investments, materials, staff, maintenance, savings, dismantling, waste management…).

In INNOQUA project, one specific objective is to assess product costs beyond traditional approaches, including indirect costs, externalities and other.

Usually, LCC main cost categories are the following: *(i)* purchase price and all associated costs (delivery, installation, insurance, etc.); *(ii)* operating costs, including energy, fuel and water

[11] ISO 14040/44

[12] ISO 14040/44

use, spares, and maintenance; *(iii)* end-of-life costs, such as decommissioning or disposal; *(iv)* externalities; *(v)* savings on use of energy, water and fuel; *(vi)* savings on maintenance and replacement and *(vii)* savings on disposal costs.

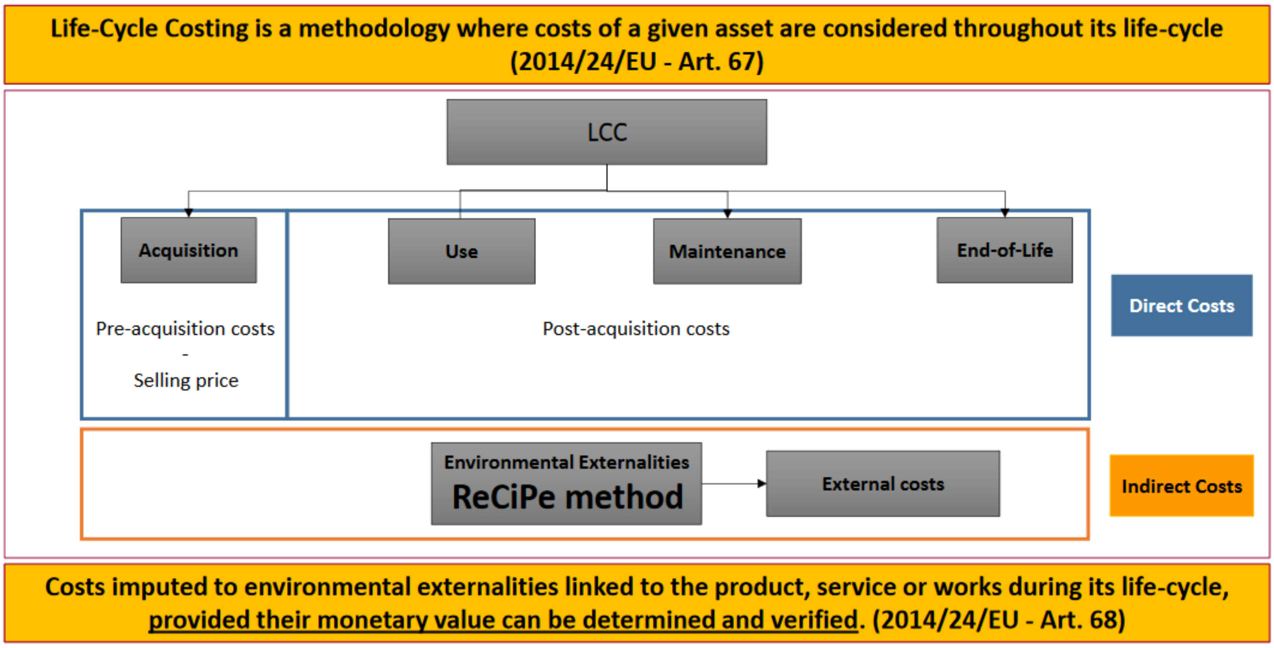

Figure 26: Life Cycle Cost (source: European Commission LCC for GPP 2015)

The ideal LCC scope is from cradle to grave and in line with the LCA scope. However, if limitations arise in terms of assessing exploitation or decommissioning costs, scope could be reduced to a cradle to gate approach.

Externalities can be defined as “the costs and benefits which arise when the social or economic activities of one group of people have an impact on another, and when the first group fails to fully account for their impact”, according to European Commission project series about energy externalities[13].

Externalities are included in a LCC but quite often not enough data is available for a robust calculation. However, general data about estimated economic cost of health-related issues due to lack of sanitation systems is available and will be included in the analysis.

4.1.3 Evaluation steps

The environmental and economic evaluations will undergo the following scheme:

a) Screening of current technologies in terms of environmental performance and costs
b) Setting the environmental and economic targets for INNOQUA solutions
c) Setting up the scenarios (INNOQUA scenarios to be tested and alternatives to be compared to)

13 Pickel et al., 2005, ExternE Externalities of Energy Methodology 2005 Update, European Commission, DG Research.

d) Simplified LCA and LCC (includes definition of scope, collection of data, impact and cost assessment…) – integrated as a supporting tool for the design process. Collection of data needs a strong implication from project partners. Results will be calculated using separate operational modules (Lumbrifilter apart from Daphnia filter and so on) in order to address the variations in final plant configurations. Results will be communicated to the design partners in an iterative process with the aim to fulfil (and review when needed) previously defined targets.
e) Complete LCA and LCC. It consists of a final validation of the adopted design and a solid basis for potential environmental certifications.

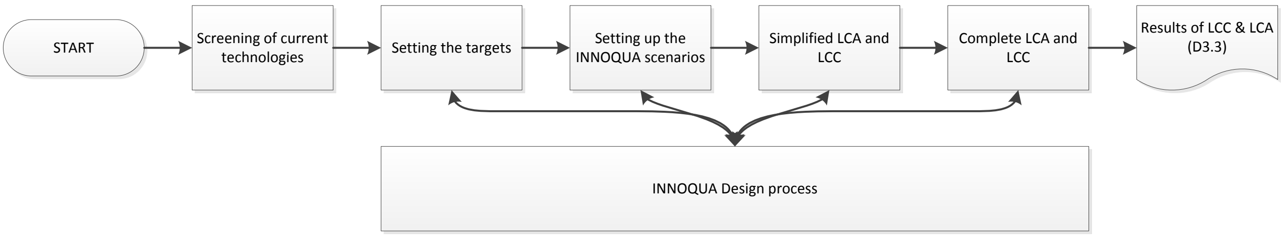

Figure 27: The steps of Environmental and Economic Assessment and its interaction with the design process

4.2 Environmental Technology Verification (ETV) Program

The EU-ETV Pilot Programme, operating as one of the initiatives under the Eco-Innovation Action Plan of the European Commission, has been set out to establish the foundations for a true European-level tool supporting and promoting eco-innovation, mainly in highly dynamic and innovative Small and Medium-sized Enterprises (SMEs). The programme is targeted at environmental technologies whose value cannot be proved through existing standards or certification schemes and whose claims could benefit from a credible verification procedure as a guarantee to investors. In a first stage the Pilot Programme is currently running in specific Technology Areas which could then be expanded in the future as the Programme becomes further implemented.

One of the reason to perform the ETV program in INNOQUA is that it is recommended for technologies when innovative features or technical/environmental performance are not fully reflected in existing product standards. For example, INNOQUA is an innovative wastewater treatment technology that might produce higher quality effluent whilst using less energy than current technologies. ETV would consider many performance parameters together including energy consumption, enabling a useful comparison with relevant alternatives.

Other reason is that ETV focuses on parameters quantifiable and measurable through testing that are related to the performance of a technology and its environmental added value. The environmental added value is considered from a life-cycle perspective, just taking into account the main benefits and impacts during the life cycle of the technology, but with a simplified approach. ETV does not have the same objective or provide the same information as specialised environmental tools based on life-cycle information such as Life-Cycle Analysis (LCA) or Product Environmental Footprint (PEF).

Finally, the EU ETV pilot programme embeds adequate standards of quality into the procedures, Figure 28. Organisations undertaking the verifications under ETV pilot programme, hereafter referred to as 'Verification Bodies', must be accredited by national accreditation bodies, using the ISO/IEC Standard 17020 for inspection bodies. The General Verification Protocol (GVP) must be integrated in the documentation describing the accredited inspection activities of Verification Bodies. In other terms, the GVP defines an inspection scheme with the meaning of ISO/IEC 17020.

4.2.1 Goals of ETV

Environmental Technology Verification is a tool to help innovative environmental technologies reach the market. It consists of the validation of the performance claims put forward by technology manufacturers, on a voluntary basis, by qualified third parties. This should help manufacturers prove the reliability of their claims, and help technology purchasers identify innovations that suit their needs.

The ETV pilot Programme, run by the European Commission on an experimental basis, is implemented by Verification Bodies (VBs) specifically accredited for ETV. The technical reference defining ETV procedures and requirements is the General Verification Protocol. It ensures that all verifications made in Europe follow the same process and have the same value. VBs are coordinated by thematic Technical Working Groups, at European level, providing guidance on the implementation of ETV and ensuring the adequate harmonisation of practices.

ETV is neither a label nor a certification scheme, it ensures that the claims are as structured and complete as possible so as to present a clear assessment of the entire technology's potential and value, but it does not evaluate the technology's performance against standard or regulations. The information provided, in the form of a Statement of Verification, gives the possibility for direct and objective comparison between different technologies reducing the risk on adopting new technologies and encouraging informed and sound investments. ETV results could be used to prove compliance with any relevant legislation, to convince investors or customers of the reliability of performance claims and to avoid having to repeat demonstrations for different users. It also allows to convince and win buyer’s confidence, facilitate adoption of the technology, ease market scale-up and discussions with financial bodies.

Even though the ETV is a procedure in itself, several parts of the process can be useful to the management of the INNOQUA project and in order to ensure a quality control of the completed tasks, such as Quick Scan document and General Verification Protocol. In addition, several countries are currently launching national initiatives to promote the use of ETV as a development tool (i.e. a guideline for the development of a technology). This is the philosophy adopted in the INNOQUA project, where ETV will be used not only to validate the final performances of the system but also to elaborate the testing phases and associated development requirements.

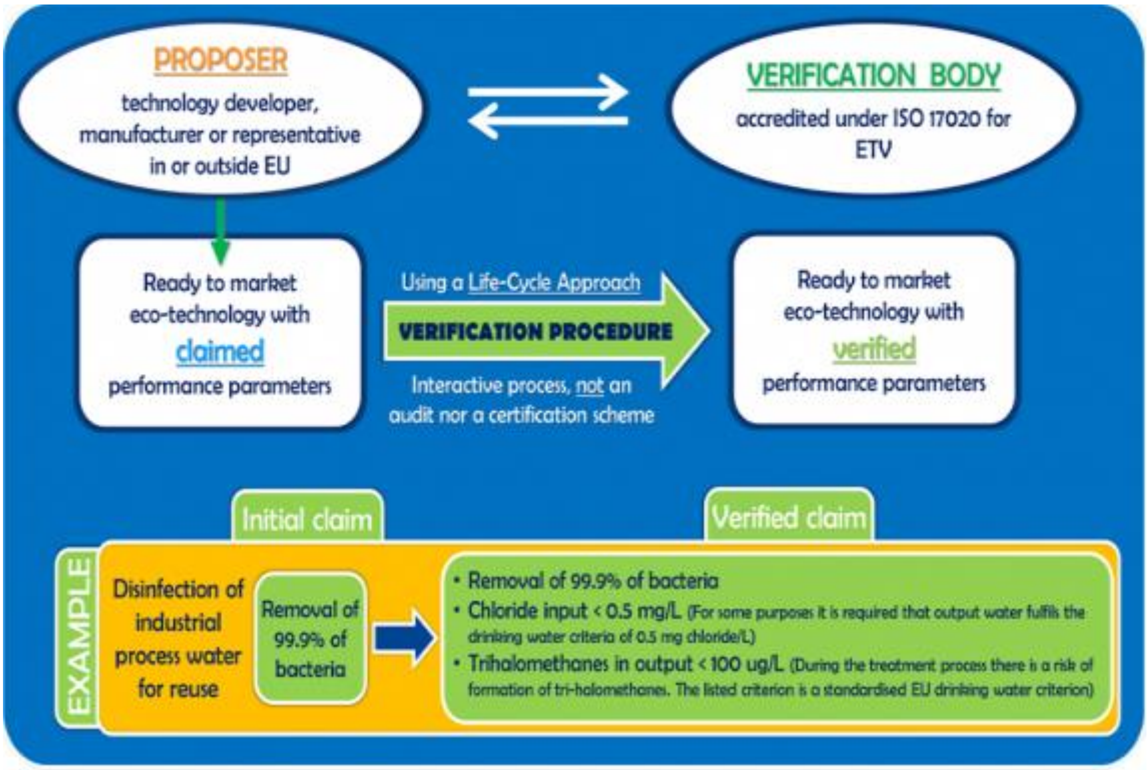

Figure 28: Overview of the ETV procedure (Source: European commission)

4.2.2 Procedure of ETV obtaining

ETV process is as described In Figure 29. It consists of six phases: *(i)* Contact Phase to start the contacts with the Verification Body and assess the eligibility check of the project; *(ii)* Proposal Phase to provide the information needed by the Verification Body to conclude a verification contract; *(iii)* Specific Protocol Preparation Phase to develop the specific verification protocol (summary description of the technology, definition of verification parameters, requirements on test design and data quality, requirements on test and measurement methods and assessment of existing data and conclusions); *(iv)* Testing Phase to perform additional tests if necessary; *(v)* Assessment and Verification Phase to the assessment of the data and review of test procedure; and *(vi)* Publication Phase where the finally the results of the assessment are published.

Initially, the INNOQUA efforts will be focused on Contact Phase in order to check the eligibility of INNOQUA technology for verification. As a first step, a Quick Scan document will filled in and sent to the Verification Body. Then, the Verification Body either recommends the technology for a full verification or not, based on the quick scan results. Then if the technology is considered to be eligible and if INNOQUA project decides to perform the verification, the next steps will be discussed in order to advance the ETV program. Therefore, this section will be probably be expanded in the next iteration of this deliverable (M10) including the next steps.

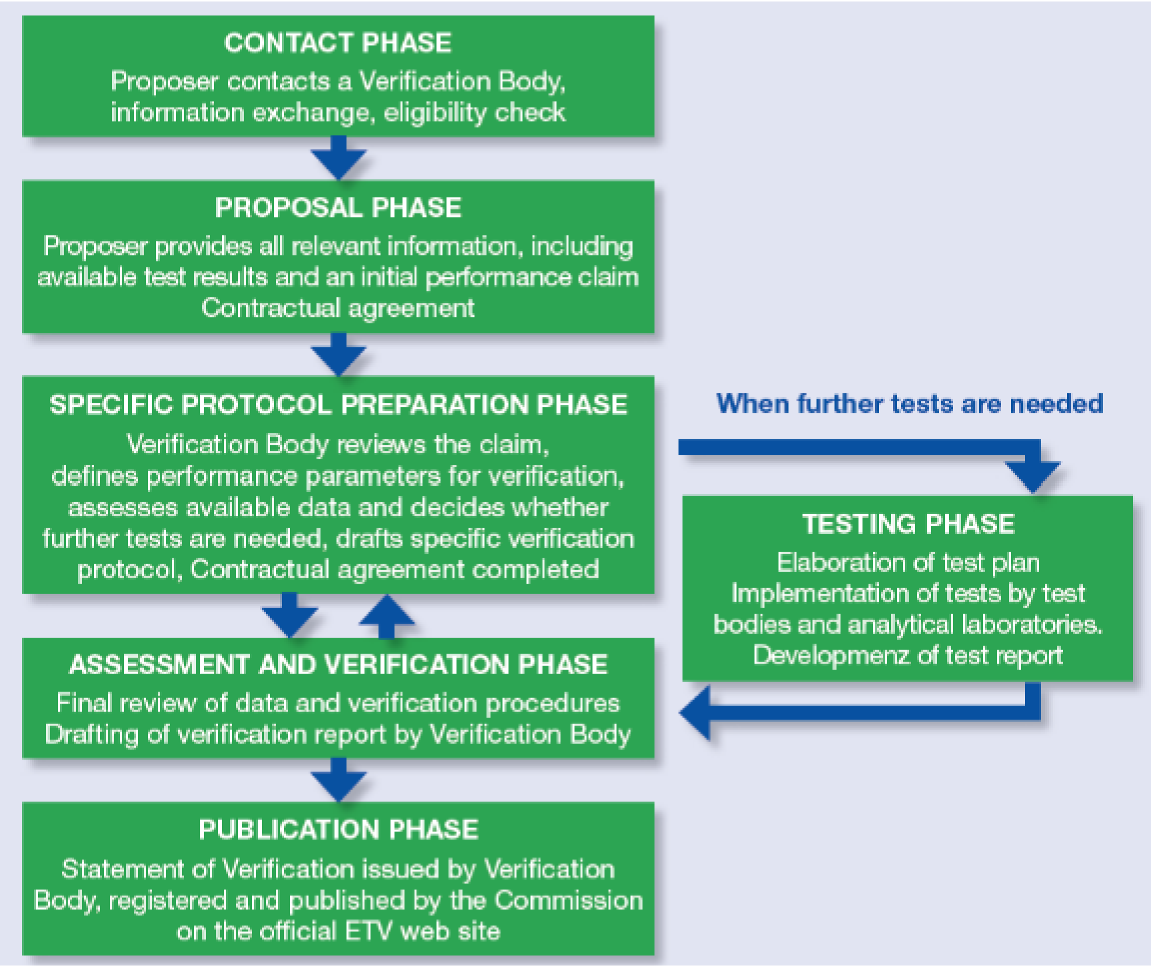

Figure 29: Steps to the ETV process (Source: European commission)

Nevertheless two main documents allow to frame the INNOQUA Project. First, the Quick Scan document which gives an overview and borders to the project, it can be considered as a document of the ETV process but also as a guideline for the project. Second the General Verification Protocol (GVP) which is a document referring to the protocol of measurement and analysis to be conducted for obtaining the ETV.

Quick Scan

The eligibility check is the first assessment made by the Verification Body, on the basis of the 'Quick Scan document' provided by the proposer at the beginning of the verification procedure.

The aim of the Quick Scan is to enable the Verification Body to assess the suitability of the technology for verification, and to give a first indication about the complexity and range of costs for a full verification. Where appropriate, the Verification Body first provides advice on the drafting and completeness of the Quick Scan. The Quick Scan is assessed by the Verification Body using the following eligibility criteria:

a) Is the technology description sufficiently clear? Are the preliminary elements for the performance claim specific to the technology and verifiable?
b) Does the technology fall within the scope of the EU ETV pilot programme?
c) Is the technology ready for the market?, for example is the technology available on the

market, or if not, is it available at a stage where no change affecting performance is likely to be implemented before introducing the technology onto the market (full-scale or prototype scale with direct and clear scale-up instructions)?

d) Does the technology present an environmental added value?
e) Does the technology meet user needs in terms of functionality, claimed performance and environmental added value?
f) Does it perform in line with applicable legal requirements?
g) Does it show a sufficient level of technological innovation?

The answer from the Verification Body includes information on the eligibility of the technology and on the corresponding technology area. The Verification Body makes a recommendation on performing a full verification or not and a first indication of the range of costs. The Verification Body shall exclude a technology from verification if it does not fall within the scope of ETV, if it is not ready to market or if its performance, environmental added value and innovation levels are obviously too low and would harm the reputation of the ETV scheme. Apart from these cases, the decision to proceed is made by the proposer, even when the Verification Body does not recommend performing the verification.

Beyond these goals the Quick Scan document is also a guideline for the INNOQUA project itself. Indeed the document allows to ask the questions about the geographical borders of the project, its aims, and the expected market for example but also to compare point of view of the different partners. In practice Quick Scan allows project partners to ask good questions and well define the framework of our objectives. These questions help to organise a global vision of the expected benefits within the project but also for end-users. It helps to put on paper the context, the issue that the technology wants answer. Questions are subdivided into *(i)* general description of the technology; *(ii)* market readiness; *(iii)* innovation level; *(iv)* potential to meet user need; *(v)* fulfilment of legal requirements; *(vi)* environmental added-value; and *(vii)* intellectual property rights. As the first question of the Quick Scan addresses (see below), likely answers are numerous. A unique question such as the issue that the technology try to solve permit to discover different answers. Indeed scope of the initial problematic can be wide redefine and discuss with partners.

Referring the general description of the Technology, it explains briefly the specific problem(s) or opportunities your technology wishes to address. For instance:

Technology has for main purpose to offer solution to the following problems in the field of sanitation:

- Difficulty or impossibility to connect buildings to sewage network. Because building can be very far from the network or because it is very expensive to achieve this construction.
- High energy consumption of waste water treatment plant processes.
- Use of chemical components into waste water treatment plant processes.
- Degradation of freshwater ecosystem quality leading to decrease of likely drinkable water sources and deterioration of biodiversity. This aspect is linked to the direct discharge of waste water without treatment into the natural ecosystems.
- Non-adapted on-site sanitation systems on the market (surface consuming, skilled staff compulsory, high frequency maintenance needed, waste production, high cost solutions).

Also after this preliminary question Quick Scan give the opportunity to reach other basic but critical questions. Indeed we have to well define relevant alternatives to the raised issue and chose in the first question. This state of the art need to define what should be the benefit of the INNOQUA technology against the existing ones.

Beyond definition of the issue, benefits of the technology, benchmark of existing technologies Quick Scan allows INNOQUA to ask question about markets. Actually a technology has to be define for a specific market and it has to be modular whether different markets are targeted. Question such as following are provided by the document:

- Is the technology already on the market?
- If no, is there a prototype or a demonstration unit available?
- Which are the main claim(s) on the technology's performance that would need to be verified?

More legal question are also provided by the Quick Scan especially concerning regulations on the target market. These question address the market issue and compliance of technology with this target. Then, Intellectual property rights are reached in order to define ownership of the technology or in the case of INNOQUA of the assemblage of technologies leading to a whole system.

Quick Scan is a document permitting to setup a framework for the implementation of the technology while no regulations exists yet. Asked questions are simple but lead to a large range of answers and permit to start discussion with partners to define the goals, the needs and clarify expected situations.

General Verification Protocol

The General Verification Protocol (GVP) supports the development and implementation of the ETV process. The GVP consists of three main sections and appendices:

a) Environmental Technology Verification (ETV) pilot programme
b) Verification procedures
c) Quality management
d) Supporting documents (appendices)

The GVP serves as the main technical reference for the implementation of ETV procedures by participating entities as well as the coordination of the programme at a European level.

The purpose of the GVP is to provide the organisational and technical framework and procedures required to support the provision of independent and credible information on new environmental technologies. Performance claims put forward by technology developers and manufacturers are verified as being complete, fair and based on reliable test results. Under ETV, test results produced prior to or during the verification process are thoroughly reviewed in order to assess the performance of the technology against relevant parameters. Mutual recognition of verification results is ensured in the European Union by following the procedures as laid down in the GVP.

5 Pre-Market and Technical Requirements Compliance

The objective of this assessment is focused on aligning the INNOQUA solution with the market. A comparative analysis of the pre-market requirements as defined in WP1 and the technical requirements defined in WP2 is carried out as part of WP3 T3.1 "*Early Models and assessment*". This process provides an opportunity, at an early stage, to review and validate the emerging design of the INNOQUA solution, to apply corrections or to redirect focus as necessary.

The validation methodology for the requirements (see Figure 30) is based on an iterative checklist evaluation. The checklist lists the requirements needed to reach INNOQUA objectives categorised as: *(i)* operational; *(ii)* engineering; *(iii)* environmental; *(iv)* economic; and *(v)* ICT.

Operation – Requirements of the INNOQUA solution that relate to the day to day performance, operation and maintenance of the system;

Engineering – Requirements relating to the installation, design, manufacture, construction and specification of the system;

Environmental/Societal - Requirements of the INNOQUA solution that relate to controlling the potential societal or environmental impact of the system;

Economic – Requirements that relate to controlling the overall cost of financial impact of the system;

ICT – Requirements relating the characteristics of the hardware and software necessary to implement the overall ICT architecture of the system.

Initially, each requirement will be reviewed with the work carried out in WP2 and Subtask 3.1.2 relating to the early models. Where validation that a specific requirement identified by the pre-market or technical analysis will be met is premature, the later Work Package that will address the issue will be referenced e.g. in an objective (e.g. growth of algae in the tanks has been observed) or analytical (e.g. measure the performance of the Control and Monitoring Unit on stressful situations by using JMeter) these will be addressed in WP4 and WP5 by prototype and demonstration site testing.

The comparative assessment described is carried out by sub-task 3.1.4 "*Review of compliance with pre-market requirements defined in WP1 and technical specifications defined in WP2*" and its results will be presented on D3.3 "*Report on final design assessment including LCA and LCC assessment*". Basically, these results will include suggestions and recommendations to be taken into account in order to enhance the early models towards optimised models. Once the suggestions and recommendations are applied, a new evaluation of the checklist is performed whose results are also depicted in the D3.3. The requirements compliance procedure is a cyclic process that following its initiation in WP3 will progress along the project development in order to define the optimised real scale systems ready for the exploitation.

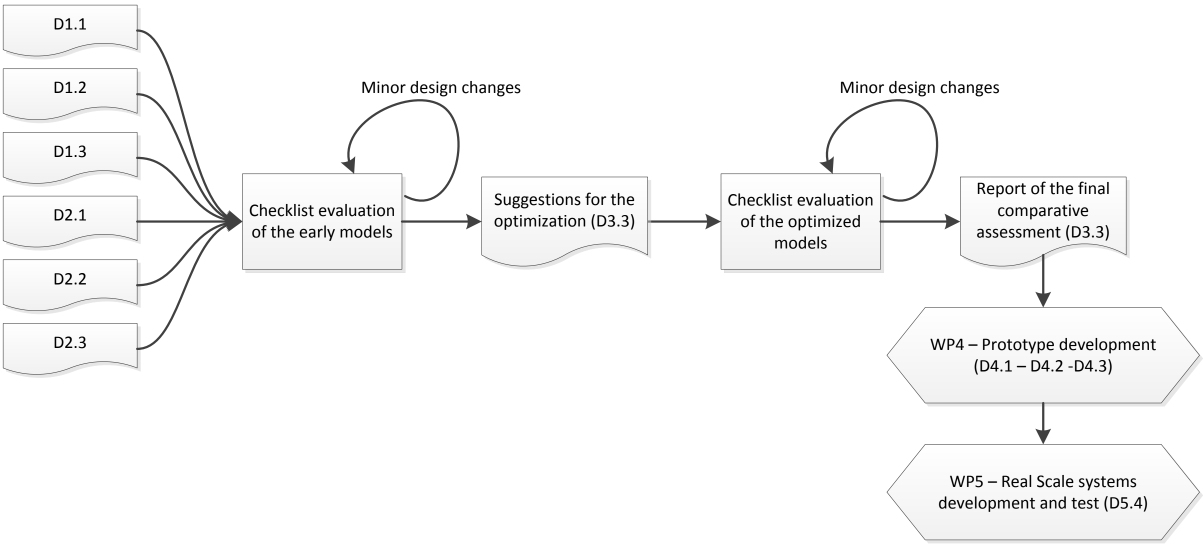

Figure 30: Assessment process of the pre-market and technical requirements

The pre-market requirements are identified by the following WP1 Deliverables:

(i) D1.1 *"Regulation, certification and standard review report"* (M6) that compiles the pre-market requirements for the INNOQUA systems;

(ii) D1.2 Pre-market study, including partial market surveys, social and acceptance behaviour parameters;

(iii) D1.3 State-of-the-art review of ICT for wastewater management focusing on biological on-site systems.

The technical specifications are defined by the WP2 deliverables:

(i) D2.1 *"Effluent physico-chemical and microbiological specifications (including maintenance requirements and shut-down prevention requirements"* (M6) that exposes the expected water effluents physico-chemical and microbiological quality parameters for the different markets and the maintenance and shut-down prevention requirements;

(ii) D2.2 *"Engineering and structural specifications (including monitoring requirements and specifications)"* (M12) that documents the technical specifications of the INNOQUA solution.

A first draft of the checklist presentation structure to be used in the validation methodology is shown in Table 5. This will be completed by the comparative assessment. The 'item' column will contain the different pre market / technical requirements to be validated which will be classified by a category. A comment regarding the status of each of the items will be entered in the specific column and, if necessary, also the corresponding future task/WP where further developments regarding each items will be provided is pointed out.

Table 5: Example of requirements validation checklist

Category	Item	Compliance Comment	Refer Item to future Task/WP
Economic	e.g. X cost of plant construction per treatment capacity of 10 pe		
	e.g. Emission of bad odours		

Category	Item	Compliance Comment	Refer Item to future Task/WP
Environmental/Societat	e.g. maximum waste generation of X gr per metre cubic of treated water		
Operational	e.g. the pH of the discharge water should be in range X to X.		
Engineering	e.g. the maximum average ascending flow in the daphnia tanks is X m/h		
ICT	e.g. the MCU manages four simultaneous sensors with sampling frequencies of X Hz		

6 Conclusions and future work

This document has introduced the test plan that the INNOQUA project will take to assess the early models' design, optimise them and address them to the market taking advantage of virtual models. It has specified which tests will be performed, their goals and which will be their processes.

Moreover, the triple assessment defined previously will allow the evaluation of the INNOQUA early models from different points of view such as: *(i)* design by simulating 3D components and analysing the ICT architecture on stress situations; *(ii)* microbiological by studying the living organisms' behaviour through real experiments; *(iii)* operational by evaluating the ICT architecture behaviour on normal and beyond conditions and testing INNOQUA solution in controlled environments (WP4) and demonstration sites (WP5); *(iv)* environmental by analysing the life cycle and life cost of the INNOQUA solution and aligning with ETV program; and *(iv)* requirements compliance by checking continuously of them.

Based on this deliverable, foreseen activities in the frame of the test plan will be focused on:

(i) enhancing the early ICT architecture taking advantage of the WP4 and WP5 feedback if necessary;

(ii) optimizing and re-assessing the 3D models for lumbrifilter and daphniafilter to assess taking advantage of WP4 and WP5 outcomes;

(iii) performing real simulations for daphniafilter, lumbrifilter to address microbiological issues in the WP4;

(iv) enhancing the LCA & LCC analysis taking advantage of the WP4 and WP5 feedback if necessary;

(v) following-up of WP4 and WP5 activities to not lose sight the new requirements and specifications of the INNOQUA technologies and feeding the requirements validation checklist;

Summarising, this plan provides a comprehensive report outlining how the INNOQUA early models will be evaluated to achieve a robust solution that complies with pre-market requirements defined in WP1 and technical specifications defined in WP2. The result of these evaluations will be depicted in the D3.3 "*Report on final design assessment including LCA & LCC assessment*" (M16).

7 Appendix A

Figure 31 shows a conceptual diagram of the INNOQUA ICT architecture which is based on three main components: *(i)* one or more "*Data Sampling*" component to capture the measures through the sensors (see bottom of the figure); *(ii)* a "*Gateway*" component to manage the data supplied by the "*Data Sampling*" component/s; and *(iii)* a "*Monitoring and Control*" platform contained in the "Gateway" component to provide a management Graphical User Interface (GUI) to the INNOQUA users.

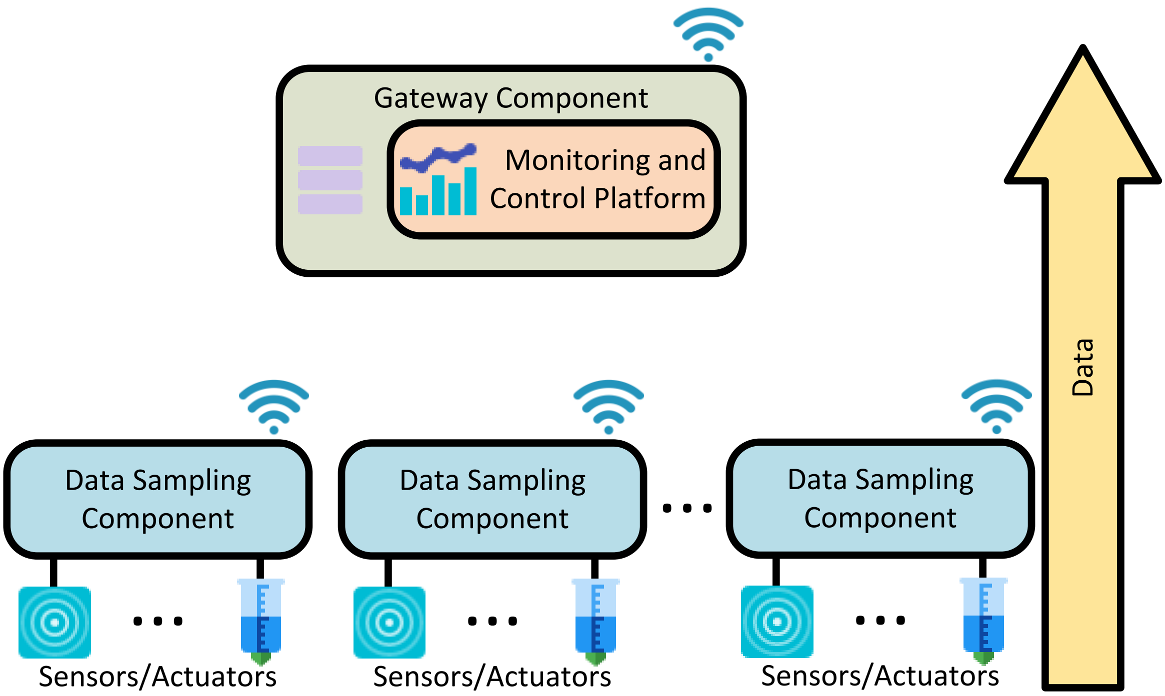

Figure 31: ICT conceptual architecture

The INNOQUA MCU solution will be composed by all these components. Multiples data sampling components will be required to manage the sensors and actuators of the INNOQUA technologies (e.g. a component to measure the temperature and pH of the Daphnia tank, other component to measure the ammonia level of the lumbrifilter outflow, pumps, mixers, UV lamps aerators…). The INNOQUA "*Gateway*" component will manage the "*Data Sampling*" components persisting the measures obtained by them and the "*Monitoring and Control*" platform will be deployed in the "*Gateway*" component allowing to apply actions and notifications based on the measured data (e.g. notify a shutdown prevention, switch on a solenoid valve…).

8 Bibliography

Burns, C.W. (1969). Relation between filtering rate, temperature and body size in four species of Daphnia. Limnology and Oceanography 14, 693e700.

Schalau, K., Rinke, K., Straile, D., Peters, F. (2008). Temperature is the key factor explaining interannual variability of Daphnia development in spring: a modelling study. Global Change Ecology 157, 531e543.

Pau, C., Serra, T., Colomer, J., Casamitjana, X. and Kampf, R. (2013) Filtering capacity of Daphnia magna on sludge particles in treated wastewater. Water Research. 47: 181-186.

Serra, T. and Colomer, J. (2016). The hydraulic retention time on the particle removal efficiency by Daphnia magna filtration on treated wastewater. International Journal of Water Science and Technology.

Serra, T., Colomer, J., Pau, C., Marín, M. and Sala, Ll. (2014). Tertiary treatment for wastewater reuse based on the Daphnia magna filtration-comparison with conventional tertiary treatments. Water Science and Technology. 70(4): 705-711.