



**D1.7 -
Water
Efficiency Applications
Framework for the Process
Industry
(Intermediate report)**

**WP1 - Water Efficiency Enhancement Applications
Framework and Baseline Assessment**

30/11/2023

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ABSTRACT	<p>Deliverable 1.7 is the output of Task 1.5 activities under Work Package 1 of the AquaSPICE project. This deliverable presents interim work of the application of the conceptual Water Efficiency Framework (WEF) for the process industry. The framework is designed in a circular shape to reflect the continuous, iterative and adaptive process of enhancing water circularity, with the goal being to reach the desired outcome of advancing the sustainable water use of process industries. The framework also focuses on aspects related to the independent understanding of digital, process and circular innovations integrated with other aspects of industrial water efficiency. It also determines synergies, options, parameters and methods used to integrate the components that comprise each solution, to make them fully interoperable and defines how they can be implemented in the factory and throughout the value chain, thereby avoiding conflicts. In this deliverable, the framework is partially applied in Case Study 2 and Case Study 5 adopted according to the feedback through its application. As part of the iteration process, the WEF is able to build upon the lessons drawn from the project period and the feedback from the case studies.</p>		

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ABBREVIATIONS/ACRONYMS

AquaSPICE	Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations
CoP	Community of Practice
CPS	Cyber-Physical System
DPSIR	Drivers, Pressures, State, Impact and Response model of intervention
EEA	European Environment Agency
EU	European Union
ISIC	International Standard Industrial Classification of All Economic Activities
SotA	State of the Art
SWOT	Strengths, Weaknesses, Opportunities and Threats
WEF	Water Efficiency Framework
WP	Work Package

1. Executive summary

Deliverable 1.7 is the output of Task 1.5 activities under Work Package 1 of the AquaSPICE project. This interim report is an iterative process of validating the framework with project Case Studies (2&5) as a demonstration. The report has started setting the scope of the process industry and addressing the challenges of industrial water efficiency. Thus, demonstrating the need for a framework to provide a guideline to improve the given case study. The WEF contains 4 phases with several steps in each Phase. In this interim report, Phases 1-3 validation has started and the key insights are reported in here. Phase 4 of the framework (Policy development and Dissemination Activity) will be validated when enough development and insights are gained from WP7 and will be reported in the final deliverable at the end of the project. The validation process requires time and resources, and it is not yet feasible to validate all portions of the framework at once as work is still being carried out in relevant work packages (WPs 6-8). The portion of the framework that is not validated or demonstrated using different Case Studies will be pointed out in the report to ensure the framework is used appropriately and that the results are interpreted correctly. This deliverable also provides the definition and process of how this conceptual framework is developed. The background and unique opportunities of each Case Study are analysed to ensure that the framework has good coverage to account for the vast diversity of the differences in the process industry without compromising on the systemic approach in water management where efficiency can be achieved through an adaptation of appropriate technologies and practices on different levels.

2. Introduction

2.1. Background

The AquaSPICE (Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations) project is a European Union (EU) funded project under H2020-EU.2.1.5.3. The project aims to materialise circular water use in the European Process Industries and to increase awareness in resource efficiency for industrial applications from a single industrial process to an entire industry via (see **Fehler! Verweisquelle konnte nicht gefunden werden.**):

1. water treatment and reuse technologies,
2. closed-loop recycling practices and
3. development of a cyber-physical system controller including a system for real-time monitoring, assessment and optimisation of water use and reuse at different interconnected levels.

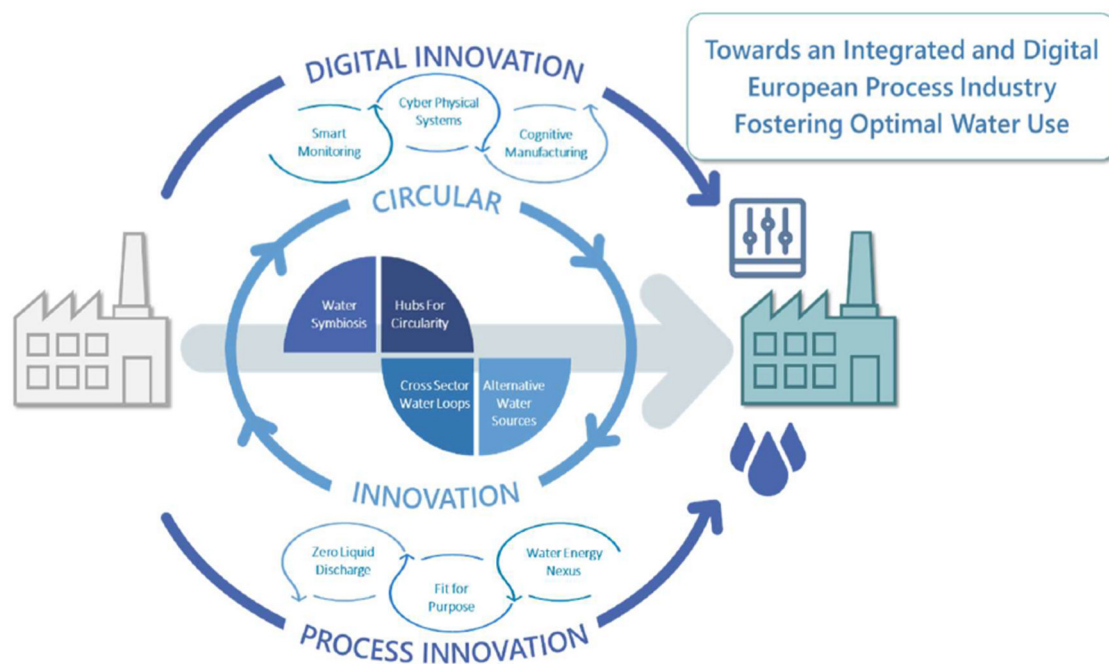


Figure 1 – AquaSPICE’s 3 pillars towards a water efficient process industry.

AquaSPICE follows a systemic approach in water management where optimal efficiency can be achieved through an adaptation of appropriate technologies and practices at different levels, from a single industrial process (unit operation) to an entire factory, to other collaborating industries (industrial symbiosis) or other sectors (e.g. domestic and/or agriculture).

AquaSPICE enables and facilitates the immediate uptake, replication and up-scaling of innovations, by providing comprehensive strategic, business and organisational plans that offer a range of well-defined and pre-packaged solutions, suitable for various cases with quite different characteristics.

Work Package 1 (WP1) of AquaSPICE is the development of a “Water Efficiency Enhancement Framework and Baseline Assessment”. It formulates the scientific, institutional/regulatory, industrial and commercial background for the development of AquaSPICE technological innovations, with an aim to satisfy the requirements of Process Industry actors/stakeholders and technology providers. WP1 consists of five tasks with Deliverable 1.4 being the development of a conceptual water efficiency framework for enhanced water efficiency and assessment and optimisation procedures, also referred to as the AquaSPICE Conceptual Water Efficiency Framework (WEF).

2.2. Defining the Scope for the Process Industry

The process industry is a series of operations that involves the physical or chemical transformation of materials, substances or components into new products. This includes the processing (recovery) of waste into secondary raw material as defined by the International Standard Industrial Classification of All Economic Activities (ISIC) [1]. However, the precise definition of the process industry can be somehow vague. For example, the pasteurisation of milk is a part of the process industry, however, the bottling of pasteurised milk is classified as discrete product manufacturing even though both processes are under the same value or manufacturing chain. Thus, when considering efficient water use, it is more beneficial to consider the business chain as a whole rather than only focusing on a singular operation in the process chain. The grey area is especially prominent when an operation such as production and distribution of chilled water through cooling towers for cooling purposes is supplied for multiple process operations along the process chain.

2.3. Challenges of Industrial Water Efficiency

Being one of the main economic pillars in Europe, industrial water accounts for about 20% of the freshwater resources and is used for a variety of processes ranging from using it as raw material, in manufacturing processes and operations, as dilution, for washing and cooling of the process units.

The freshwater consumption for industrial usage is varying between countries but the consumption is predicted to grow by a factor of 5 in industrialisation developing countries. This increase in usage usually results in a higher volume of wastewater to be discharged, coupled with the variation in strength, variability and composition (including heavy metals, solvents, toxic sludge, and other accumulated wastes) of the wastewater, will cause additional challenges to the public sewer and the environment [2]. Industrial wastewater effluents typically originated from sanitary wastewater, cooling tower, process wastewater and cleaning wastewater from cleaning and maintenance of industrial areas. However, in some cases the extent of industrial wastewater generation remains largely unknown due to a deficiency in the available data and information [3]. Very often, the huge potential of industrial (waste)water management is underappreciated and has become a barrier to overcome to complete the transition towards a more circular economy.

2.4. Promoting Industrial Water Circularity

The concept of circular water management and ‘closing the water loop’ has gained attention in the industrial sector to improve the environmental impact of industrial activities. One of the factors that lead to this approach is that water is becoming a scarce resource. Due to the current linear model of economic growth, degraded (waste)water is becoming unfit for further use by humans or the ecosystem. Furthermore, the total water withdrawal by industry is much greater than the water consumed, indicating the way water being consumed can be improved by a better efficiency scheme [4]. This can be achieved by adopting a holistic approach with innovations at water re-use solutions (State of the Art (SotA) practices and water re-use technologies) in different closed-loops levels (in-process and in-factory closed-loops as well as a symbiosis with other industries and sectors) as demonstrated in Fehler! Verweisquelle konnte nicht gefunden werden.. The system can be further advanced by coupling advanced digital solutions (such as online sensors) for real-time monitoring and integrated under a novel water cyber-physical system (CPS).

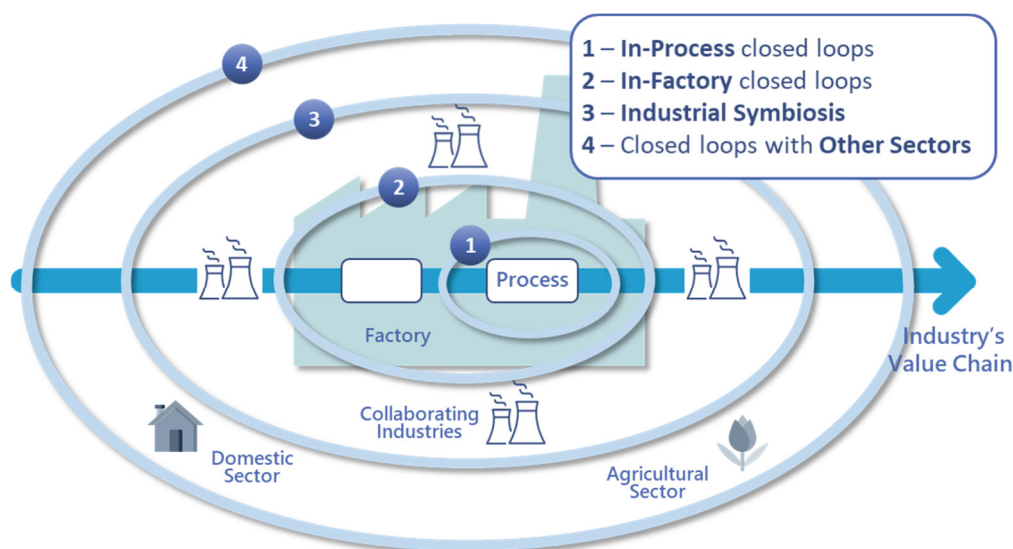


Figure 2 – Systemic approach in water management where water efficiency can be achieved in different levels: a single industrial process (unit operation), the entire factory, other collaborating industries (industrial symbiosis) or other sectors (e.g. domestic and/or agriculture)

3. Development of a Water Efficiency Framework (WEF) for the process industry

3.1. What is a conceptual framework and what is a water efficiency framework?

A conceptual framework is a convergence of networks of interrelated components and variables, which help in solving a real-world problem. It can also be defined as the explanation of the key concepts or variables of a topic of interest and the relationships

between them that need to be studied. It can be designed in many different ways but more commonly in the form of a written or visual representation [5]–[9]. Through the aid of a conceptual framework, the user should be able to demonstrate the way key concepts (i.e. Digital, Process and Circular innovations for AquaSPICE) and their variables will converge to inform the phenomenon.

The overall objective to develop a novel and comprehensive WEF in AquaSPICE is to develop guidance with respect to enhancing water efficiency in the process industry by framing and outlining the architecture of the integrated technological solutions that encompass all aspects of industrial water use, recovery, treatment and re-use, all potential sources and opportunities for re-use of recovered water. The WEF also aims to provide an effective organisational, regulatory and business framework for the process industry. For this deliverable, the conceptual WEF will be portrayed diagrammatically using a concept map to relate the aforementioned ideas and aspects.

3.2. The need for a Water Efficiency Framework

Due to the rapid development of industrial activities globally, the demand for the world's limited supply of resources has increased, including water. The traditional linear business model in the industrial sector is no longer sustainable nor friendly to the finite water resources. While there has been an increase in the industrial awareness of the adverse effect the process industries bring to the global water supply, the potential of an integrated process-circular-digital innovation approach of advancing the industrial circular water use remains unexploited. Such a circular approach can be advanced through drivers such as the influence of political, environmental and economic pressures or benefits. On the other hand, the progress to achieve a more efficient industrial water use is often hindered by gaps in the available network, technology, psychological or financial factors or a more appropriate framework. In some cases, the barrier of transitioning from a conventional linear approach to a circular approach in industrial wastewater management is due to cost arguments whereas others are due to the lack of a supportive framework. While several EU regulations, guidelines and directives have helped define a framework for advancing circularity in the process industries, these initiatives are mostly broad but with room for improvement. This massive potential will have to be realised from a regulatory point of view and shaped with the aid of an appropriate framework of incentives and industries focused guidelines.

3.3. Development of the Water Efficiency Framework

The goal of this conceptual framework is to provide a structural organisation to the segregated data and to frame these data into information that supply knowledge to the relevant parties and stakeholders; that in turn creates an understanding of supporting industrial water efficiency at the policy level and for practical applications at the industrial level as demonstrated in **Fehler! Verweisquelle konnte nicht gefunden werden.** A holistic water management framework requires relevant performance metrics and these metrics are derived from the systemic integration of various data depending on accurate information resulting from a holistic assessment.

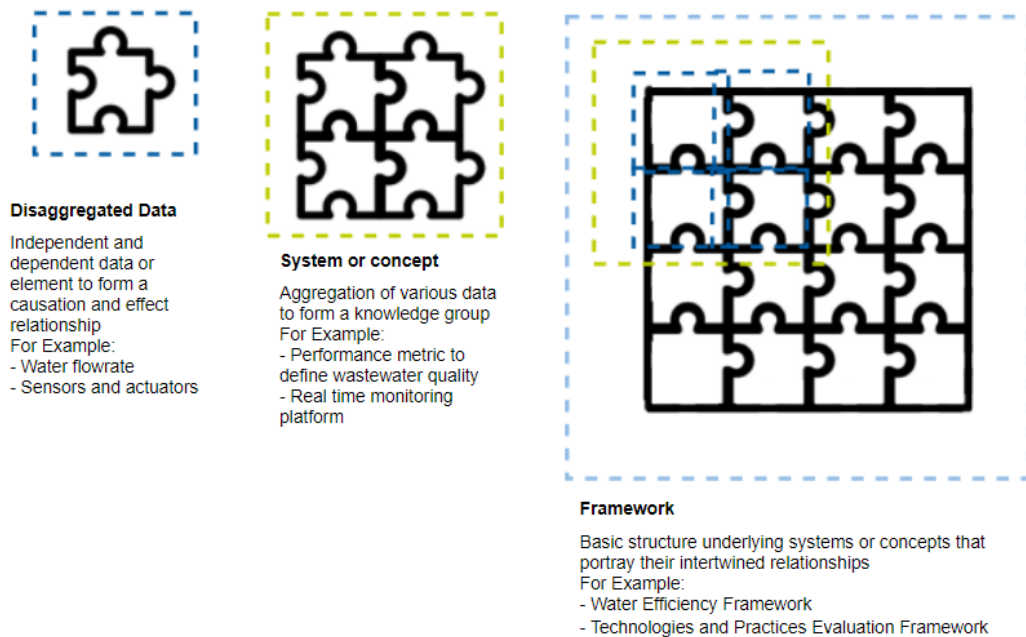


Figure 3 – Examples of some building blocks for the industrial WEF

The development of this framework will be focussing on the circularity performance of industrial water along the process chain, which includes the abstraction, use, treatment and reuse of water. Apart from framing and outlining the architecture of the integrated technological solutions offered by AquaSPICE, the framework will also provide guidelines and other input both for supporting industrial water efficiency at the policy level and for practical applications at the industry level. Such an approach will normally require a cradle-to-cradle approach that unites and recognises the value chain users. Thus, the environments and requirements of the full spectrum of potential (end)users and uses are crucial to understanding and beneficial to unlock watershed possibilities. Hence, the elements of stakeholders will also be incorporated into the conceptual WEF. Furthermore, the framework will define holistic monitoring, assessment, optimisation and management procedures and rules, as well as standards/benchmarks, goals and potential targets for relevant water efficiency practices and solutions that can be adapted, tested and validated by the use cases throughout the project duration, thus providing a comprehensive and systemic integrated architecture for industrial water management. These elements are summarised in Fehler! Verweisquelle konnte nicht gefunden werden. below.

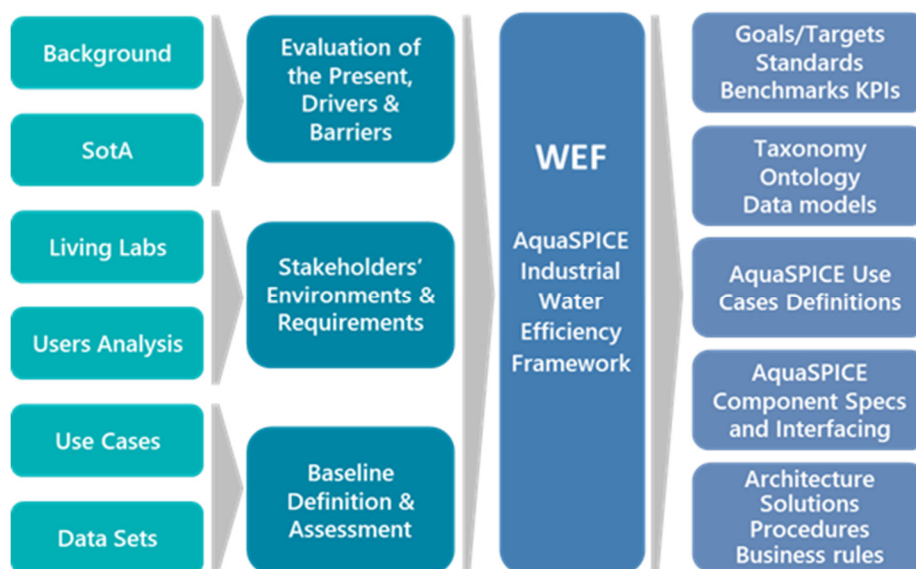


Figure 4 – Elements to be included in the WEF

A range of different environment-related conceptual frameworks has been developed over recent years to help with the identification and assessment of relevant indicators, or to illustrate the relationship between policies and theories [10]–[14].

The development process for this framework will be adopting the DPSIR (Drivers, Pressures, State, Impact and Response model of intervention) Framework as an underpinning model. The DPSIR model is widely adopted by the European Environment Agency (EEA) is an integrated approach for reporting [15]. The skeleton of the DPSIR framework shown in **Fehler! Verweisquelle konnte nicht gefunden werden.** demonstrates the causal chain links of the elements to be included in a DPSIR framework, which has previously been demonstrated in other water centric projects, such as, for ‘ecological river restoration’ in Stockholm, Sweden, and for ‘water uses and related water quality issues’ in the Colombian Alto and Medio Dagua Community Council [16]–[18].

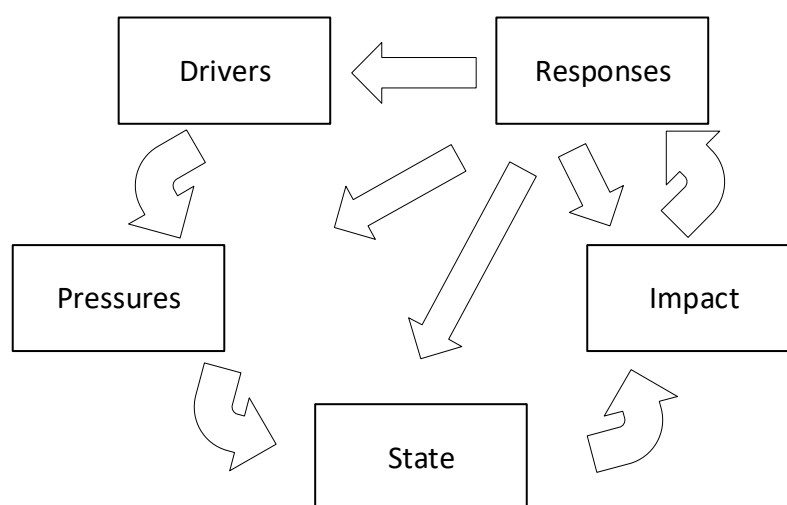


Figure 5–The skeleton of a DPSIR framework (adapted from [15])

4. Front Runners of AquaSPICE Solutions

4.1. Background

AquaSPICE’s innovations regarding holistic water management are driven by several business cases in the process industries. As shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**, multiple Case Studies, involving industrial actors of different sectors will be the early adopters of the innovations (deployment and assessment of SotA water recycling technologies and practices and the novel WaterCPS) offered by AquaSPICE. The variation in the Case Studies has provided a large variety of opportunities and challenges to be explored and tackled within the project period.

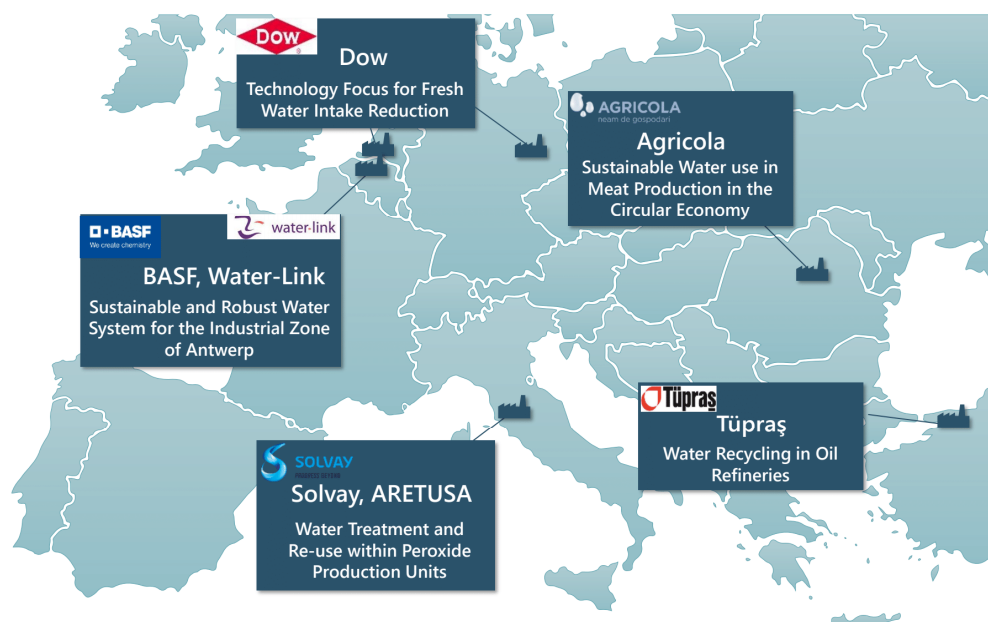


Figure 6– AquaSPICE Case Study locations

4.2. Case Study #1- Technology focus for freshwater intake reduction at Dow

CS#1 is divided into two subcases, namely Dow Boehlen and I-Parc Dow Terneuzen. Dow's businesses include speciality chemicals, advanced materials and plastics. Due to the tight water balance in the region south of Leipzig, the Boehlen location of Dow is classified as water scare and I-Parc Dow Terneuzen is under severe water stress as it is located in a coastal area with very limited availability of freshwater. Thus, a sustainable solution for the use of water resources is sought for long term development in both locations. Both Boehlen and Terneuzen strive to reduce their freshwater intake intensity by:

- Enhancing internal recycling of various process water streams, including cooling tower blowdown and dilution steam blowdown streams.
- Creating the next level of site water management by using smart monitoring, algorithms and control on raw water, discharge and recycle streams.

The unique opportunities identified for Case Study #1 are:

- An optimised freshwater allocation for producing cooling tower make-up water suitable to operate downstream cooling towers at significantly enhanced recycling rates;
- The internal re-use of cooling tower blowdown streams;
- The treatment and direct reuse of slightly polluted process water and dilution steam blowdown streams; and
- The digitalisation of the water reuse scheme will include the design for full digital smart control and integration in the existing water grid for current operations.

4.3. Case Study #2- Water treatment and reuse within peroxide production units at Solvay, Aretusa

The Rosignano Solvay industrial site is one of the oldest and largest in Italy. It produces sodium carbonate, sodium bicarbonate (also for pharmaceutical use), calcium chloride, chlorine, hydrochloric acid, chloromethane, plastic materials, peracetic acid and hydrogen peroxide. In order to deliver more sustainable water management, Consorzio ARETUSA was established in 2001 as Public Private Partnership among water utility (ASA Livorno), industry (Solvay Chimica Italia) and tech provider (Termomeccanica). Thanks to ARETUSA, for more than 15 years the Solvay chemical plant is implementing a utility-industry (public-private) symbiosis system for optimising the regional water cycle, by reusing about 3 million cubic meters per year of urban wastewater treated in the ARETUSA reclamation plant. The existing Waste Water Reuse Plant (WWRP) contains flocculation, sedimentation, filtration, activated carbon filter (GAC), and UV disinfection.

The unique opportunities identified for Case Study #2 are:

- Process control in the WAPERUSE processes;
- The internal re-use of cooling tower blowdown streams; and
- The treatment and direct reuse of slightly polluted process water and dilution steam blowdown streams.

4.4. Case Study #3- Sustainable and robust water system for the industrial zone of Antwerp at BASF, Water Link

The Port of Antwerp is the leading European oil and chemical cluster in Europe and home to key industrial players in chemical production. Several of these chemical companies are large water users that require water for processing products, cooling and steam production. The freshwater source that connects to the Antwerp harbour is the Albert Canal. The Albert Canal in its turn takes its water from the river Meuse. Drinking water company Water-link abstracts water from the Albert Canal for drinking water production. Due to climate change, there is increasing salinisation of the dock waters in the port, as well as of the River Scheldt and the Albert Canal. The available amount of freshwater is declining. Therefore, large water users in this region are obliged to investigate alternative water sources.

The largest water user in the port of Antwerp is the BASF site, which abstracts water from the docks for cooling purposes, water that contains a substantial concentration of salts. In case of climate change, the water quality of the harbour dock will change, and this will undoubtedly affect the management of cooling water in the system. BASF is also shifting towards a new demineralized water treatment using fresh surface water from the Biesbosch area based upon reverse osmosis (RO) technology. The concentrate from the RO will be highly loaded in terms of NaCl, very promising for possible reuse options. Additionally, BASF has a number of organically and salt loaded wastewaters that are currently not reused.

The area is, thus, facing increased problems of managing freshwater resources – for drinking water, industry and transport (inland shipping) – in terms of both water quantity and water quality. The stakeholders in the area need to develop strategies that ensure that water quality and scarcity are factored into decisions that protect current operations and support business growth. This requires the development of integrated water-smart strategies for industrial processes demonstrating water recycling technologies and real-time smart monitoring and management systems.

The unique opportunities identified for Case Study #3 are:

Digital: Development of a real-time smart monitoring and management information system for monitoring water quantity and quality to:

- Manage water allocation decisions (right quality for right use);
- Switch from current water supplies to alternative water supplies for industrial use (cooling and process water) during drought periods; and
- Assess scenarios for long term water and salt balances to develop climate adaptation strategies.

Process: Evaluation of the effects of an enhanced recirculation of cooling water at the site and examine possible future process conditions (scaling, fouling, corrosion), including modelling of the cooling system:

- To investigate and to increase knowledge of cost-effective treatments for water reuse of RO concentrate from the new demineralized water production plant; and
- To investigate and to increase knowledge of cost-effective treatments for water reuse of process condensate streams and process streams from the steam cracker plant, for direct reuse or reuse after treatment.

4.5. Case Study #4- Not Reported

Due to the non-existence of the SynDi plant in CS#4, this CS is considered as void case and no work related to this CS is reported in this deliverable.

4.6. Case Study #5- Sustainable Water Use in Meat Production at AGRICOLA

Water is a critical resource for the poultry, meat and agricultural industry. The meat industry needs to implement smarter solutions, reduce the environmental footprint and contribute to the circular economy. AGRICOLA International SA is a private meat company in Bacău County, Romania, using their poultry husbandry-specialised farms, 15 chicken raising farms and two slaughterhouses. Currently, all treated wastewater effluent is discharged into the municipal sewer network. AGRICOLA chicken slaughterhouse produces an average wastewater flow rate of about 1400 m³/day. However, there are plans for expansion of the slaughterhouse, which will result in increased production and will likely significantly increase the daily average wastewater flow rate. Thus, there is a need to optimize the design and operation of the industrial wastewater treatment plant in order to become more water efficient and introduce the concepts of circular water management at AGRICOLA. The pilot Case Study to be implemented at AGRICOLA will deploy and explore smart solutions for sustainable water reuse and resource recovery, with the objective of improving water efficiency monitoring and achieving process optimisation.

The unique opportunities identified for Case Study #5 are:

- Zero water reuse at present provides a huge opportunity to investigate, discover and initiate a circular water use approach to allow for the freshwater intake reduction; and
- Development and exploration of real-time smart monitoring and management systems from the ground to monitor water quality control parameters across the process scheme.

4.7. Case Study #6- Water Treatment and Re-use within Refinery at TUPRAS

The oil and gas refining industry are highly water intensive, requiring vast amounts of water, used as cooling water, service water, firefighting water, demineralisation water and steam production. A refinery also has closed-loop water reuse opportunities embedded in the production line (e.g. drum wash water, stripped sour water, desalter, make/up water, coke-cutting water). Tüpraş is the first producer in Turkey's refining sector and the largest industrial enterprise of the country, operating four oil refineries with a total annual processing capacity of 30 million tons of crude oil. The Tupras Izmit Refinery is consuming both freshwater from the lake and treated wastewater from its wastewater recovery plants. During maintenance operations or in case of capacity problems, the refinery relies heavily on the lake. In order to increase the water reuse opportunities and decrease freshwater intake from the lake, any attempt approaching the near-zero discharge goal is considered seriously.

The unique opportunities identified for Case Study #6 are:

- A blending of the streams will be optimised to decrease the amount of water discharged to the receiving water body;
- Monitoring tools will be used to decide whether the contaminated water will be used for the subsequent processes or discharged to the sea; and
- Aim towards the near-zero discharge goal, by decreasing the freshwater intake from the lake and recovering at least 50% of contaminated water which will be fed to the new pilot plant developed under the scope of this project.

5. The Conceptual Framework

AquaSPICE aims to reduce the industrial water demand and losses, to treat and recycle water as well as exploit alternative water sources through technological advancement in the digital, process and circular innovations. This conceptual framework aims to synthesise the interrelated components and variables within the scope of AquaSPICE to attempt improving efficiency of water use in the process industries. This encompasses all aspects of industrial water extract, use, recovery, treatment and re-use, all potential sources and opportunities for re-use of recovered water, within the factory, in pre-and post-production processes, across its value chains, as well as in industrial symbioses and closed-loops with other economic sectors.

These elements of the framework should be all well integrated, and not overly complex or expatiate in order to have wider applicability. Therefore, this conceptual framework aims to provide a modular, concise, systematic step yet with room for flexibility to enable adaptive implementation in individual cases towards water efficiency enhancement. This adaptive approach will be demonstrated in the Case Studies and summarised in the final report for WP1, Deliverable 1.6: Water Efficiency Applications Framework for the Process Industry. The AquaSPICE Conceptual Water Efficiency Framework is developed in a circular approach and is composed of four phases as shown in **Fehler! Verweisquelle konnte nicht gefunden werden.:**

1. Evaluation of As-is Situation and Target
2. Investigation
3. Assessment and Expected Output
4. Policy Development and Dissemination Activity

The procedures and steps in these phases are triggered when there is a change in the contexts of industrial water efficiency, very often, factored but not limited to:

- Demand and supply management
- Social change
- Regulatory instruments
- Climate Change impacts
- Economic instruments

These changes are sometimes unpredictable and hence the steps in the Conceptual Framework are designed in a way where the process is devised in an adaptable loop and

regular feedback and improvement can be carried out throughout the project cycle and even revisited when new contexts (drivers or challenges) occurred within the scope of the framework. An important aspect in the development of this framework is its ability to provide unique solutions to respond and accommodate multiple outcomes. However, like in any framework, periodic checks and revisions of the components in the framework would be necessary to ensure it is progressive and still remains fit for purpose.

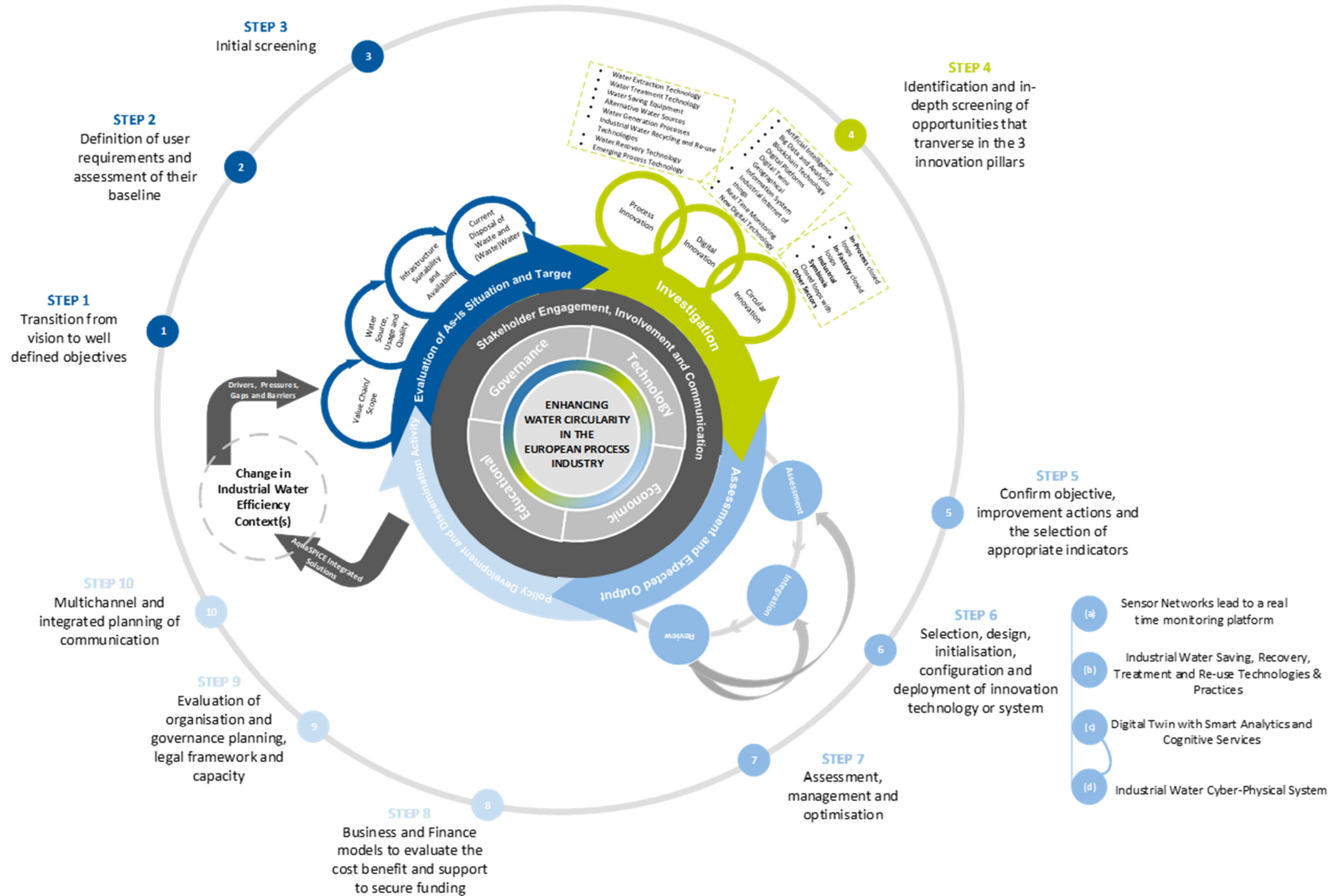


Figure 7– Conceptual Water Efficiency Framework for AquaSPICE

5.1. Phase 1: Evaluation of As-is Situation and Target

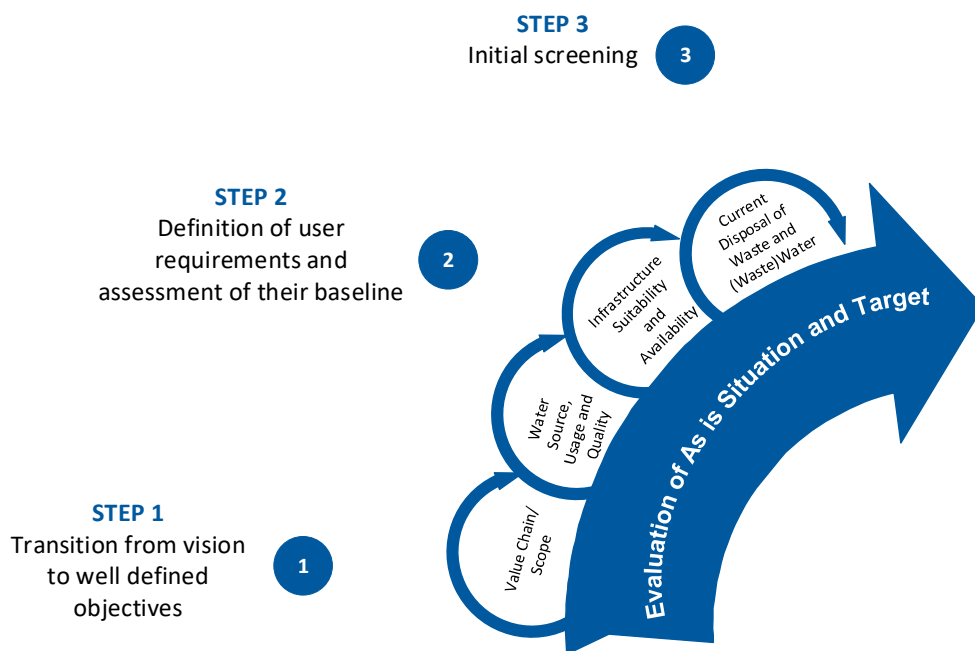


Figure 8– Evaluation of as-is situation and target

5.1.1. Step 1: Transition from vision to well-defined objectives

The AquaSPICE overall goal is the development and validation of water efficiency management and optimisation methodologies, technologies and tools that will carry the process industry forward to a neutral water footprint target with minimum freshwater consumption and water-borne emissions. It is important to set the vision right in the initial phase of a project and a vision that resonates with the work of AquaSPICE should be concise, clear, oriented towards efficient water use in the process industry. Having a clear vision might be more complicated in large and very complex projects. However, it aids to maintain clear direction when processes face challenges of increased complexity. Thus, it is crucial to translate these visions to well-defined and measurable objectives which can be used to quantify and differentiate whether a process has used water efficiently.

5.1.2. Step 2: Definition of user requirements and assessment of their baseline

The ability to meet the needs and requirements of users or stakeholders throughout the entire life cycle is crucial for the success of projects, and very often, there are many issues to be resolved during the development and implementation of any water management plan. Thus, identifying the potential stakeholders and their requirements is critical at the beginning of any project and there is a need for the prioritisation of user requirements and the synergies among them in order to effectively manage resources. A stakeholder register (see Fehler! Verweisquelle konnte nicht gefunden werden.Fehler! Verweisquelle

konnte nicht gefunden werden. as a template) can be built to streamline the process and by gathering useful information about the users.

Table 1– Potential stakeholder/ user register

Stakeholder ID / Name	Stakeholder Group	Interest	Needs	Estimated Impact	Estimated priority	Observations, concerns and opportunities	Risks
Xxxx				++	+++		

Undertaking a baseline assessment serves as the first estimation of the present state of industrial water efficiency. This step includes analysing the data obtained during the assessment to establish a measure for all the actors and stakeholders by providing information about the current condition (including water quantity and quality) and pre-existing system and infrastructure (water chain, treatment system and alternative water collection system - how are these measured, i.e. availability of (online) sensors). This information can be collected through interviews or workshops with relevant actors and systematic data collection through questionnaires and can be adapted for each site considering its particularities and uniqueness. The data describing the baseline conditions will be used as a basis in the course of the AquaSPICE project cycle to quantify the improvement gained from the selection, design, initialisation, configuration and deployment of innovative technology or system within the scope of AquaSPICE holistic approach.

5.1.3. Step 3: Initial Screening

After the establishment of an as-is situation, the next step would be the preliminary evaluation and establishment of the target situation. The initial screening step includes understanding the detailed presentation of the raw water or wastewater stream(s), the existing closed loops (intra-factory or across the value chain), and the existing ICT infrastructure (ICT systems, sensors, etc), as well as the characterisation of the water stream after the current treatment processes.

The information and data collected can then be analysed to pinpoint the needs and areas of improvement within the AquaSPICE scope, to ensure the options to enhance water circularity is fit for purpose as there is no ‘one size fits all solution’. Due to the variation in the water demands, at very different water quality and quantity requirement levels across any industrial facility, a set of preliminary KPIs that encompasses a vast universe of macro variables, allowing a top-down approach to solidify the overall aim and objectives and all of its components. These components (closed loop practices to be tested, the desired quality of the water stream treated with the proposed solution, the reuse of water, the water efficiency problem detection and the route-cause analysis and remedial action) are usually the driving force for the end goal. Best attainable conditions in terms of different options of reuse and combinations of treatment schemes can be

investigated through this approach by prioritising high value (both economically and environmentally) areas. This phase of screening also includes the investigation of relevant local permits and ethic requirements and how these legislation processes are influencing the selection and deployment of AquaSPICE’s technological solutions.

5.2. Phase 2: Inventorisation



Figure 9 – Inventorisation of opportunities and possibilities in the digital, process and circular innovations

The second phase of the framework is the inventorisation phase where the purpose of this phase is to identify and conduct an in-depth screening of opportunities that transverse into the 3 innovation pillars as shown in **Fehler! Verweisquelle konnte nicht gefunden werden..** In order to minimise business risks and maximise positive outcomes, the scope of diligent background review and novel solution considerations in the second phase will take into consideration results obtained from the first phase of the framework, which includes the scope, water chains/loops and characteristics, user requirements, local legislation and regulatory.

The main considerations for each of these innovation pillars include but are not limited to:

- **PROCESS INNOVATION:** A comprehensive set of advanced technologies and practices, combining energy and other materials recovery, are assessed within use case scope, leading to novel solutions for water saving, treatment and recycling.

- **CIRCULAR INNOVATION:** Closed-loops including water re-use options at different levels (in-process, in-factory, water industrial symbiosis, cross-sectorial) are established, considering also different water sources.
- **DIGITAL INNOVATION:** The selection of digital components to be integrated into a novel concept of a water-specific Cyber-Physical System (WaterCPS) that synthesises digital twins of industrial and value chain entities to provide advanced water-saving awareness and optimised water efficiency at different industrial levels.

Through this in-depth screening, the innovations that are not fit for purpose can be eliminated, for example, the quality requirement for water reuse in irrigation compared with that in food processing, the production of higher quality water than required can result in overtreatment, leading to unnecessary cost and overuse of resources such as energy and operation & maintenance costs. On the other hand, some options for closed-loop water reuse may be extremely vulnerable to the accumulation of a certain type of impurities. Thus, it is crucial to have the right register of highly selective separation technologies to be considered as the treatment options, and the deployment of digital innovation to aid the cognitive process that indicates the removal efficiency to optimise water efficiency.

5.3. Phase 3: Assessment and Expected Output

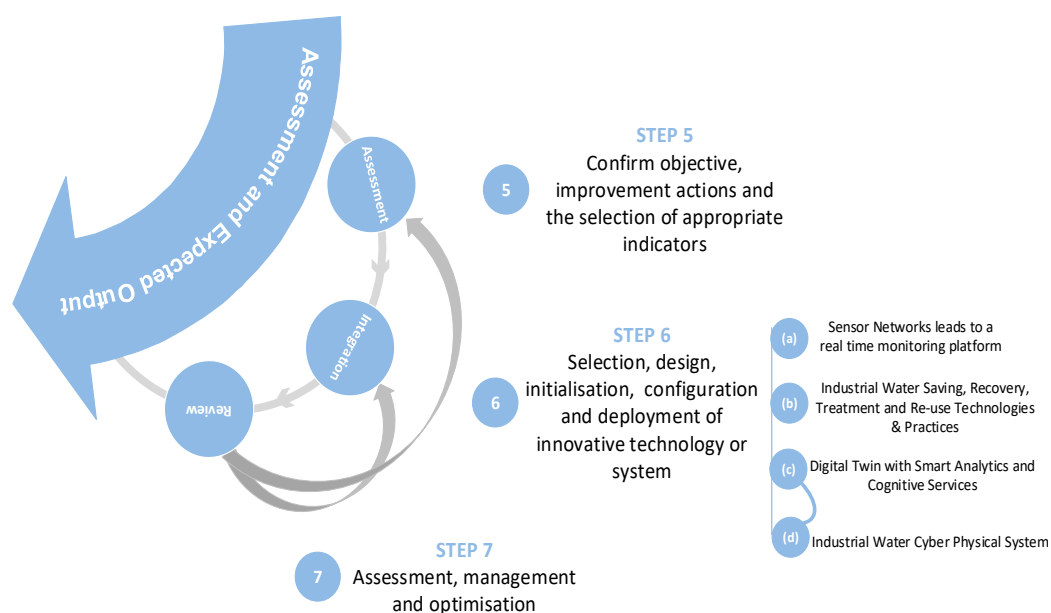


Figure 10 – Assessment of AquaSPICE solutions and expected output

5.3.1. Step 5: Confirm objectives, improvement actions and the selection of appropriate indicators

Phase 3 of the Conceptual Framework is when the information and solution gathered from Phases 1 & 2 of the framework converges and the operational objectives and target, thus the actions and directions of improvement can be confirmed. The core of Step 5 is to focus on the evaluation and integration of the screened innovations, and the

performance measurement with the aid of different tools and assessments (flagships and indicators) of the solutions.

It **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the multilevel approach to support, improve and determine the present state of water efficiency, the call for actions and the expected state of the result. The development of these novel technologies and solutions for water management and water treatment in the process industry will take into consideration several critical indicating concepts such as the water footprint and embodied energy, as well as carbon footprint [26]–[32]. An extensive list of more specific indicators can also be generated to ensure the coverage of the broad European process industry category.

5.3.2. Step 6: Selection, design, initialisation, configuration and deployment of innovative technology or system

These demonstration schemes are designed, monitored and evaluated using systematic methodologies and tools by WP2 (Industrial Water Saving, Recovery, Treatment and Re-use Technologies & Practices), WP3 (Real-Time Water Efficiency Monitoring Platform for the Process Industry), WP4 (Digital Twin with Smart Analytics and Cognitive Services for Water Efficiency) and WP5 (Water Cyber-Physical System: The Industrial Water Efficiency Management System). Furthermore, one of the key outputs from WP1 of AquaSPICE is the development of a semantic ontology (data exchange model) that interrelates processes and operational measurements for enabling a common understanding of the information. **Fehler! Verweisquelle konnte nicht gefunden werden.** **Fehler! Verweisquelle konnte nicht gefunden werden.** shows an example of the [ontology for the ULTIMATE project](#) - an H2020 project on water smart industrial symbiosis.

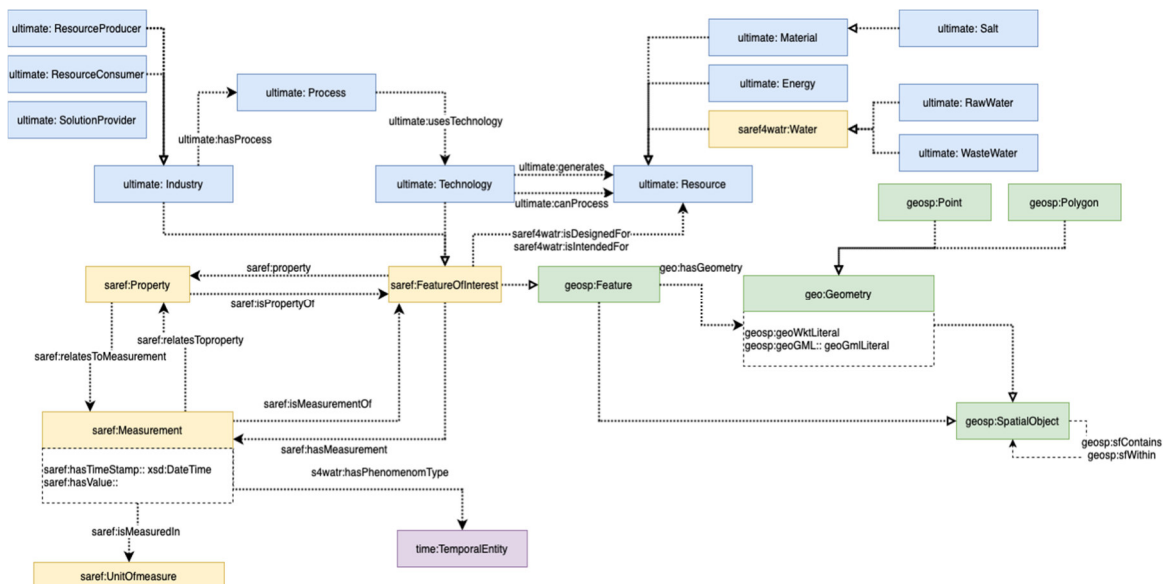


Figure 11— An example of ontology developed for the ULTIMATE H2020 project as the knowledge graph to be shared by individuals who participate in the given domain [33], [34]

Holistic modelling concepts, such as dynamic Life Cycle and Life-Cycle-Cost Assessment will be incorporated to string the work of work packages together. Through the work of

these modelling concepts, the optimal and integrated water reuse schemes (including water symbiosis) can be quantified and visualised.

5.3.3. Step 7: Assessment, management and optimisation

Following the deployment of the technologies, the assessment, the defined list of metrics and KPIs will be discussed, reviewed and revised to contribute to the assessment methods for encouraging water circularity and other water efficiency metrics. This step is crucial for enhancing water efficiency as the reduction of freshwater consumption and other resources usage requires a cradle-to-cradle approach which recognises that many processes are involved upstream and downstream of the industrial plant. Furthermore, a fine-tuning of the synergies of the combination of digital solutions with novel water recycling and re-use technologies offers a greater potential for extensive optimisation. AI-learning methodologies and WaterCPS can be used as a method of assessment and optimisation by bringing in cognitive-manufacturing methods and tools for dynamic process adaptation after root cause analysis for detecting non-optimal water use, to continuously minimise freshwater consumption

5.4. Phase 4: Policy Development and Dissemination Activity

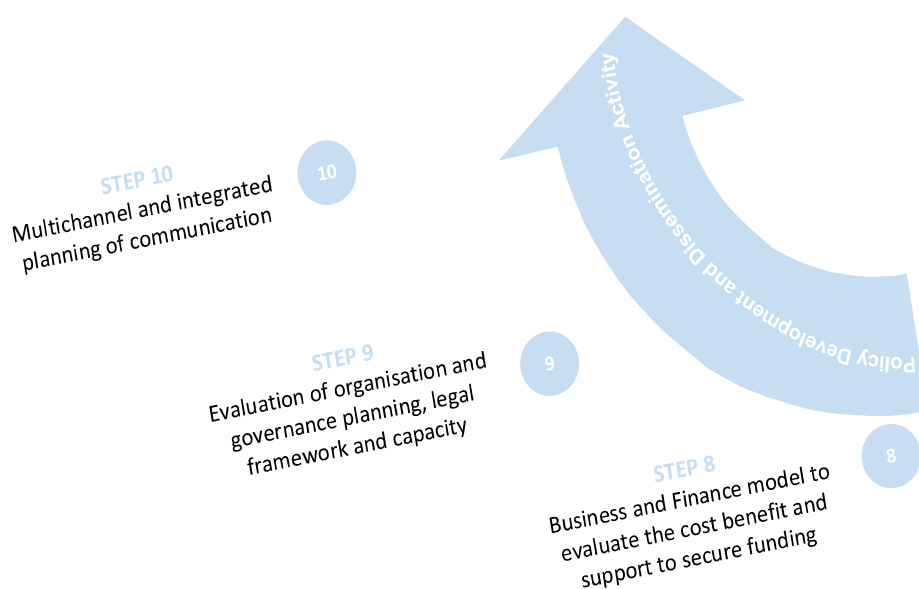


Figure 12– Policy development and dissemination activity

5.4.1. Step 8: Business and Finance model to evaluate the cost benefit and support to secure funding

To-date, there is relatively little consideration about industrial water management in terms of business models, despite the high relevance of water in human activities and societies. Thus, the funding opportunities and incentives for such activities are lacking. The overall market context, different business models, tailored financial models and public support schemes will be developed by looking at the macroeconomic context to assess opportunities and barriers of the AquaSPICE solutions. These evidence-based solutions and their uptake strategies will be thoroughly assessed to prove the cost-benefit and support the acquisition for initial financing. Through these schemes, new

business models and support market creation can be explored through a thorough analysis, profiling and sharing of business models and services for circular water opportunities in the process industry. Furthermore, these new business models and service concepts will address barriers, which have so far prevented the adoption of collaborative solutions. And finally, business and marketing support to exploit the extensive new opportunities revealed by adopting industrial symbioses and closed-loops approach, thus, ultimately improving industrial water efficiency.

5.4.2. Step 9: Evaluation of organisation and governance planning, legal framework and capacity

As discussed in Section **Fehler! Verweisquelle konnte nicht gefunden werden.**, the management of water resources and satisfying user requirements is an adaptive management task. It is beneficial to have an enabling government framework. In order to realise AquaSPICE's vision of materialising circular water use in European Process Industries, fostering awareness in resource-efficiency and delivering compact solutions for industrial applications, it is complex to tackle all the uncertainties from an integrated perspective and on contrary, these uncertainties will need to be captured to allow continuous adaptive management. To enable this, AquaSPICE delivers an assessment of current European policies, regulations and standards to provide recommendations for the technical, organisational and regulatory framework and guidelines for changes. Furthermore, an evaluation of the existing water and industrial standards will be evaluated in terms of their applicability to the technological approach to boost the technical development of the project and also the market uptake of such technology. The learning from these activities can then be linked to the local context and thus streamline and standardise the process of decision making and the outcome is a unique organisation and governance planning that are tailored to the individual project. As such, existing but also future consensus-based standards, focusing on open standards, will create a firm basis for technical procurement, support communication through standardised terminology and concepts and ensure interoperability, fitness for use and market relevance.

5.4.3. Step 10: Multichannel and integrated planning of communication

One of the challenges and barriers pointed out in AquaSPICE Deliverable 1.1: Approaches to Industrial Water Efficiency, Drivers and Barriers is the challenge in enhancing industrial water efficiency is not only finding the right technology but also understanding the cultural perceptions and implications (i.e. the 'yuck' factor) on (waste)water reuse to encourage water circularity. Thus, an effective continuous plan is required. The wider community can be disseminated to maximise the project impact. This can be achieved via a knowledge users' analysis that describes and details related companies, disciplines, technical profiles, generic & specific competencies and other key educational issues. The AquaSPICE consortium will also play its part by building a curriculum to share the knowledge and findings. This can then be used as a portfolio to be incorporated into the integrated planning of communication activities such as market research, Strength, Weakness, Opportunity, Threat (SWOT) analysis, marketing strategy, audience analysis,

creative briefs, public relations, advertising, new media, campaign development, return on investment, and evaluation.

6. Validation of WEF in Case Studies

The validation of a conceptual framework is an essential step in ensuring that the framework is reliable and can be used to achieve the intended objectives. According to a study by the University of Pretoria, the validation process involves testing the theoretical constructs in a real-life context [35]. To validate the conceptual framework, a Case Study can be used. A Case Study is a research method that involves an in-depth analysis of a particular situation or phenomenon [36]. The validation of a conceptual framework with a Case Study is an effective way to ensure that the framework is reliable and can be used to achieve the intended objectives. The Case Study provides an in-depth analysis of the situation under investigation, which helps to validate the theoretical constructs of the conceptual framework. In order to validate the WEF developed in the AquaSPICE project, Case Study#2 and Case Study #5 have been selected to validate different Phases and Steps of the framework.

6.1. Application of the WEF on a Hydrogen Peroxide Production Plant

Water is a vital resource for the chemical industry, and its efficient use is critical for sustainable development. The chemical industry is one of the largest water consumers, and it is essential to develop a framework that can help improve water use efficiency in the industry. Hydrogen peroxide is a versatile chemical that has a wide range of applications in various industries. Some common applications of hydrogen peroxide are as an oxidising agent during chemical synthesis, aseptic processing and packaging, sugar bleaching, pulp and paper industry, mining, cosmetics and pharmaceuticals, treating wastewater, textile bleaching, component of rocket fuels, producing foam rubber and organic chemicals. Section 4.3 of this report has provided some background information on this Case Study.

Phase 1: Evaluation of As-is Situation and Target

The evaluation of the as-is situation and target to assess water use in the industry is a crucial step in ensuring sustainable water use. The evaluation process involves assessing the current water usage patterns in the industry and identifying areas where water can be conserved. This is followed by setting targets for water use efficiency, which can be achieved through the implementation of water-saving technologies and practices.

- Step 1: Transition from vision to well-defined objectives

The Rosignano Solvay industrial site is part of a consortium in a collaborative scheme with public and private partners that fosters water reuse in the area. Solvay aims to further reduce water intake and increase recycling rate by considering reusing its wastewater. With the involvement of the 3 main actors, including Solvay, Consortium Aretusa WRP and the local municipalities as shown in Figure 13, the vision is transited into implementing a water reuse technology for the wastewater of peroxide and peracetic acid production from the Solvay plant

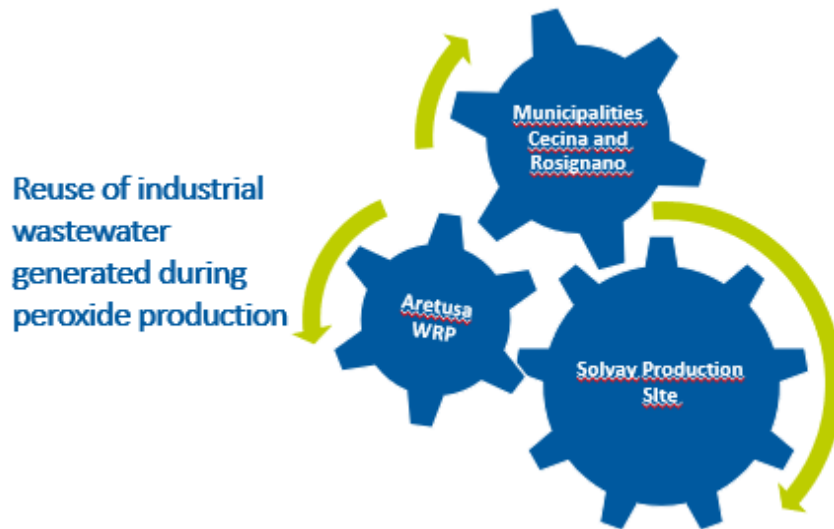


Figure 13– Main actors in Case Study #2

- Step 2: Definition of user requirements and assessment of their baseline

The definition of user requirements and assessment of their baseline is a critical step in the development of any project. For Case Study #2, the requirements baseline is a snapshot in time that represents an agreed-upon, reviewed, and approved set of requirements that have been committed to the objective of increasing water reuse set in the previous step. The baseline can then serve as a reference point for review at a later timeline.

The current treatment scheme of the Aretusa WRP is shown in stream 1 of Figure 14 with no reuse of wastewater of peroxide and peracetic acid production. Thereafter, a number of criteria were selected to be the key enablers to incorporate the wastewater as a source of production water:

- Identify key contaminants and their sources.
- Critical treatment parameters for wastewater management.
- Emphasis was placed on tower reuse to minimise chlorinated reagent use

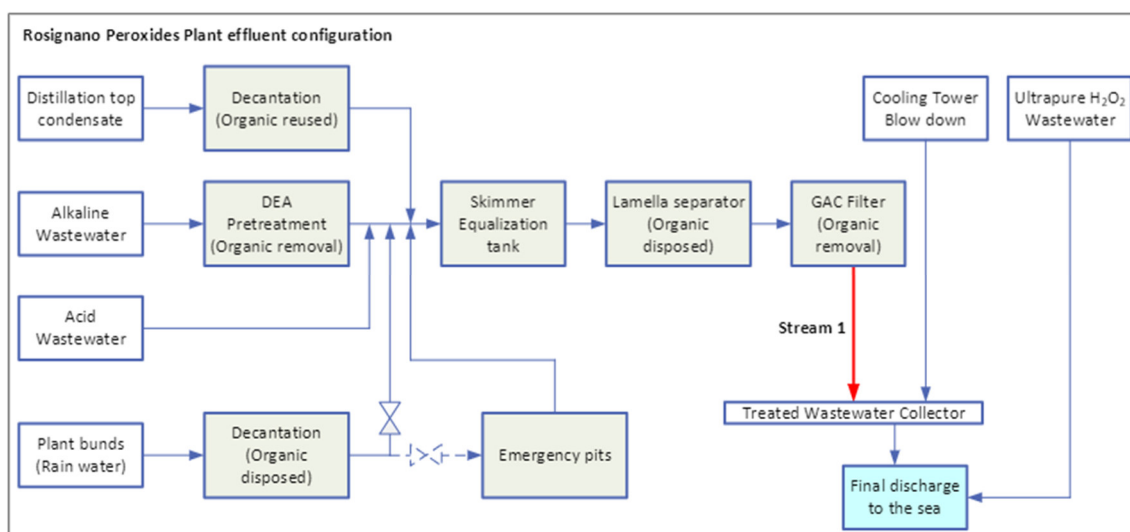


Figure 14— The current scheme of Case Study #2, where stream 1 is treated and discharged into the sea as the baseline (extracted from D1.2).

- Step 3: Initial Screening

The initial screening of water reuse opportunities from stream 1 is an essential step in identifying the potential for water reuse. The process involves assessing the quality and quantity of the water in the stream, identifying the potential uses of the water, and evaluating the feasibility of the proposed reuse options. The goal of the initial screening is to provide a preliminary assessment of the potential for water reuse and identify the next steps in the process, for Stream 1, the opportunities for reuse have been narrowed down to 3 options in Figure 15.

Opt. 1:	•Treated industrial wastewater is discharged in the urban sewer systems to be treated at Rosignano WWTP and then, at the Aretusa Water Reclamation Plant (WRP) before its reuse at Solvay plant
Opt. 2:	•Treated industrial wastewater is sent to Aretusa WRP to be further treated before reused at Solvay plant
Opt. 3:	•Treated industrial wastewater is <u>reused directly</u> at the Solvay plant for the cooling process .

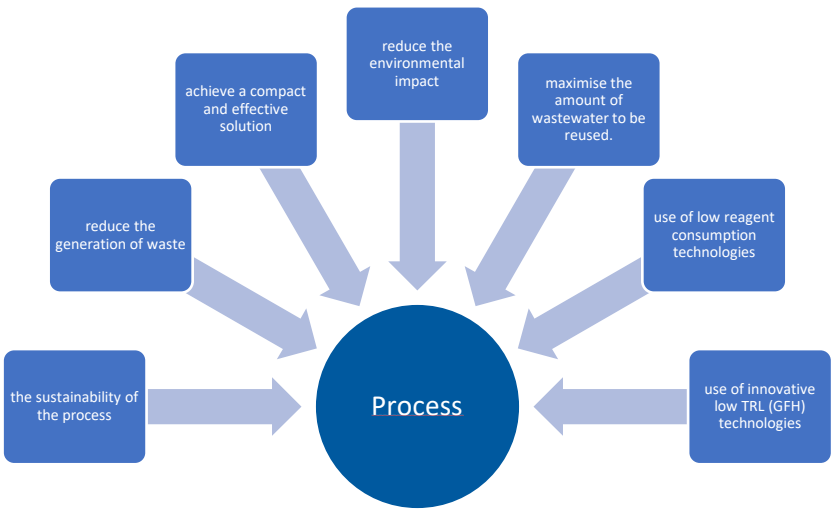
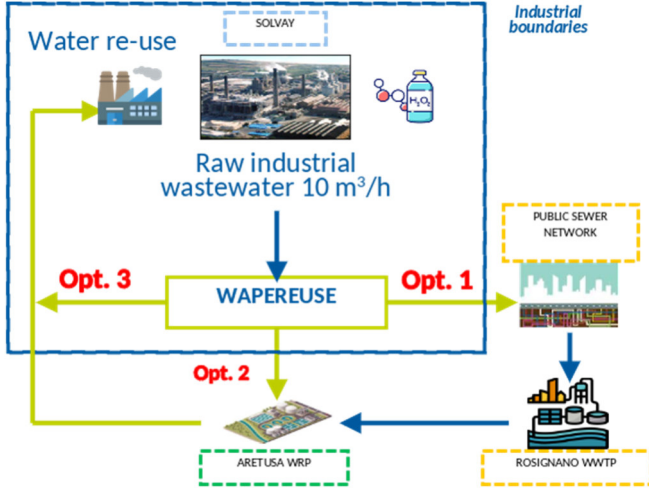
Figure 15— Initial screening of opportunities

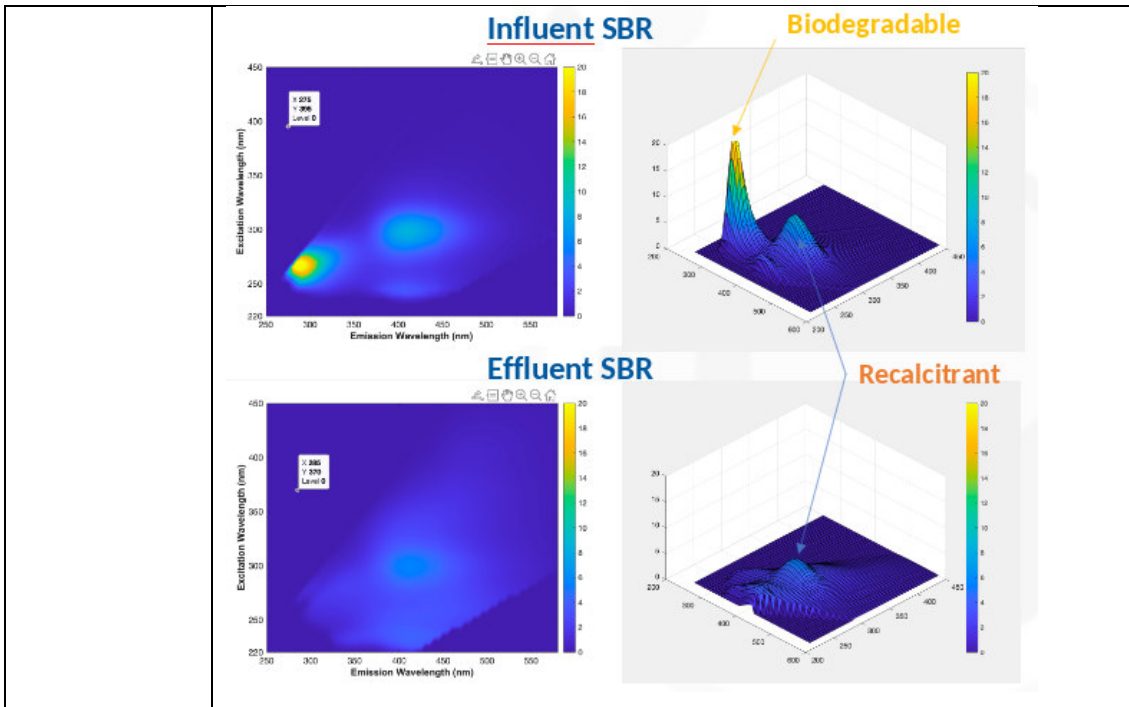
Phase 2: Inventorisation

- Step 4: Identification and in-depth screening of opportunities that transverse into the 3 innovation pillars

The Case Study reflects AquaSPICE’s approach to water management that emphasizes the importance of efficiency through the adaptation of appropriate technologies and practices. This approach is based on three innovation pillars as elaborated in section 5.2 of the report and demonstrated in Table 2.

Table 2– Developments, integrations and demonstrations of Case Study 2 in AquaSPICE's 3 innovation pillars [Extracted from AquaSPICE General Assembly 2021& 2023].

Pillars	Applications
Process Innovation	
Circular Innovation	<p>Strategic management of wastewater treated, through multiple circular options</p> 
Digital Innovation	The application of UV spectroscopy and fluorescence sensors to understand the progress of the biological process and filtration



Phase 3: Assessment and Expected Output

This phase involves evaluating the project’s performance with respect to expected outputs, outcomes, and impact. The assessment process can help identify any gaps between the expected and actual performance and provides insights into the project’s effectiveness. Whereas, the expected output is the planned result of the project, while the actual output is the result achieved at the end of the project. The assessment process involves collecting data, analysing the data, and reporting the results.

- Step 5: Confirm objectives, improvement actions and the selection of appropriate indicators

Confirming objectives, improvement actions, and the selection of appropriate indicators is a crucial step in ensuring that the implementation of circular water solutions is successful. This process involves redefining the problem statement and the scope of the work, identifying the relevant stakeholders, and setting clear objectives for the project. For AquaSPICE’s Case Study #2, the objective is reflected in the impact the industries and project partners aim to achieve, and ranked in different priorities specifically related to a goal, specifically of environmental and financial priorities, as shown in Figure 16.

KPI	Impact within the AquaSPICE project	Relative priority
Amount of reclaimed and reused water (m ³ /year).	AquaSPICE solution will increase the reuse of reclaimed water at Solvay plant.	High
Energy footprint in wastewater treatment. (kWh/m ³ or kWh/COD _{removed} or kWh/H ₂ O ₂ _{removed} or kWh/pollution load removed).	Energy for water reclamation will be compared with the energy required for freshwater intake from the local aquifer. Calculation will be accomplished for the three reuse options.	High
Carbon footprint of wastewater treatment (kg CO ₂ eq/m ³).	Carbon footprint for water reclamation will be compared with the carbon footprint related to freshwater intake from local aquifer. Calculation will be accomplished for the three reuse options.	Medium
Amount of produced waste /m ³ .	The amount of produced waste and its specific disposal will affect the environmental impact of the solution.	High
Cost of treated wastewater (€/m ³).	AquaSPICE solution will optimize the cost of wastewater treatment.	High

Figure 16— Impacts case study aimed to achieve its relative priorities and indicators to realise the impacts (Extracted from AquaSPICE Deliverable 2.2 [37]).

- Step 6: Selection, design, initialisation, configuration and deployment of innovative technology or system

The selection, design, initialisation, configuration, and deployment of innovative technology or a system for wastewater reuse is a complex process involving identifying the appropriate technology or system that can be used for wastewater treatment and designed to meet the predesigned KPIs and should be configured to optimise its performance. Case Study #2 has been achieved by a series of laboratory tests leading to preliminary data that facilitate the selection of technologies for pilot technologies selection. An example is the laboratory study on Sequential Bioreactor (SBR) led out by project partner UNIVPM, as shown in Figure 17.



Figure 17— Laboratory study of SBR and COD (key contaminant) removal for case study 2 under different process conditions. (figure extracted from AquaSPICE 2023 General Assembly meeting presentation)

- Step 7: Assessment, management and optimisation (applied to Case Study 5 – Agricola)

The assessment process involves evaluating the project’s performance with respect to expected outputs, outcomes, and impact gathered from previous phases and steps of the framework. Identifying the improvement actions that need to be taken to achieve these objectives. A method of assessment is Life Cycle Assessment (LCA), as it is a tool that can be used to identify areas where improvements can be made to reduce the environmental impact of a product or service. Figure 18 shows the environmental impact of applying different water treatment technologies and reuse for Case Study #5 as a demonstration of how LCA can be a form of assessment tool to optimise the process parameters of the selected wastewater treatment technology and to evaluate different reuse options. Case Study #5 is presented here as the status of assessment for this Case Study is more mature at this moment than Case Study #2 and able to draw a more holistic understanding and demonstration of the WEF.

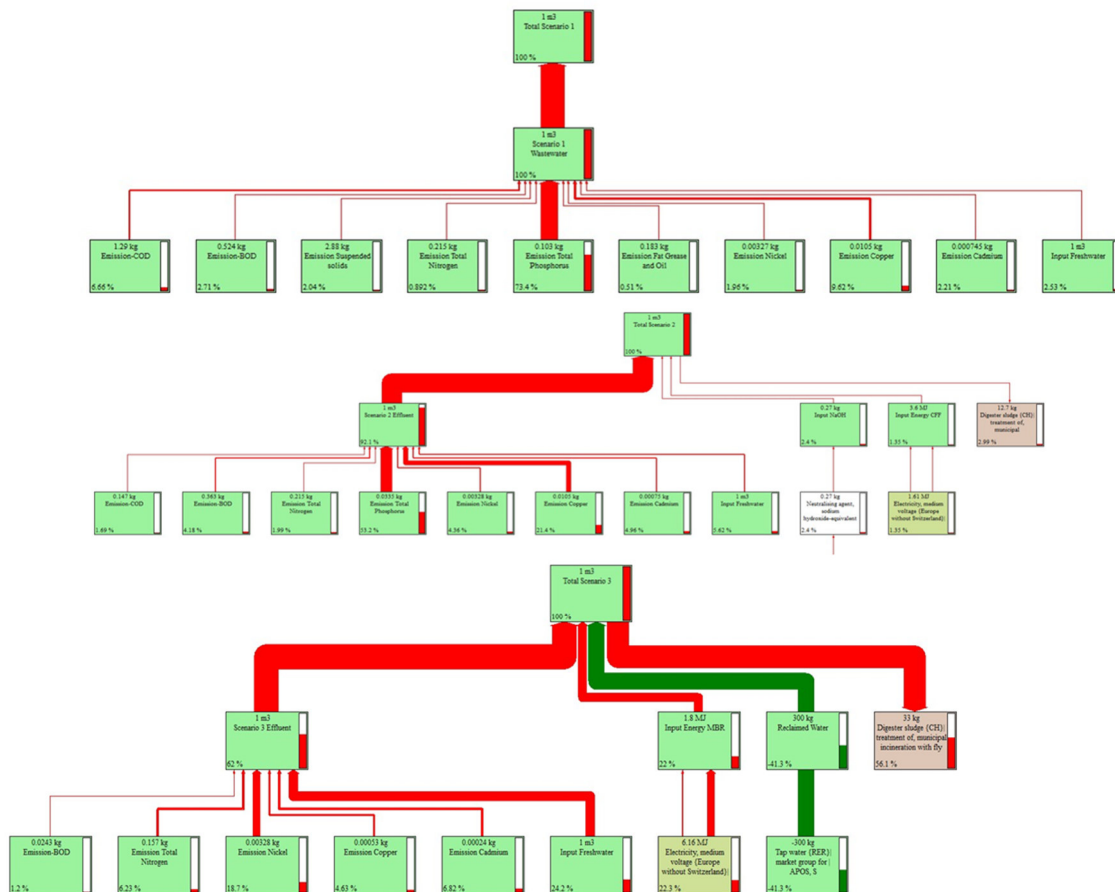


Figure 18— LCA of Case Study 5 evaluating different water technologies and the environment trade off of different reuse loops

Phase 4: Policy Development and Dissemination Activity

The 4th Phase of the framework (Policy development and Dissemination Activity) is not yet validated for this interim report. As the project is still ongoing and the validation process requires time and resources and it is not yet feasible to validate all portions of the framework at once as work is still being carried out.

- Step 8: Business and Finance model to evaluate the cost-benefit and support to secure funding

A business and finance model to evaluate the cost-benefit and support to secure funding is a critical component of any project. The model involves analysing the costs and benefits associated with the initiatives to improve water use in the industry. The model can be used to identify areas where costs can be reduced and benefits can be increased. The model can also be used to identify potential sources of funding and to develop strategies to secure funding. However, there are several challenges associated with developing a business and finance model, including the complexity of the model, the availability of data, and the uncertainty associated with the project.

- Step 9: Evaluation of organisation and governance planning, legal framework and capacity

- Step 10: Multichannel and integrated planning of communication

7. Conclusion and remaining validation activities

The AquaSPICE industrial WEF is a key output of the AquaSPICE project. Deliverable 1.7 is the output of Task 1.5 activities under Work Package 1 of the AquaSPICE project. This interim report is an iterative process of validating the framework with project Case Studies (2&5) as demonstrations. The report started with setting the scope of the process industry and addressing the challenges of industrial water efficiency. Thus, demonstrating the need for a framework to provide a guideline to improve the given Case Study. The validation of Phases 1-3 of the WEF using Case Studies and other work package activities is progressing well and has been reported in this interim deliverable. In the remaining timeframe of the project, Phase 4 (Policy development and Dissemination Activity) validation will commence and be reported. Since the project is ongoing and the coming months will provide more modelling outputs and formulation of policy scenarios, the information and insights presented here are important developments in the AquaSPICE WEF Application. In addition, this interim report wishes to serve as a summary of the current position in the AquaSPICE application WEF work and development and what can be built further upon.

It is expected that the Case Studies and project partners adopt the insights and provisions of this report. The WEF ought to be a continuous adaptive process and build upon the lessons drawn from the project period and the feedback from the Case Studies and relevant work packages.

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