



**D1.6 b -
Water
Efficiency Applications
Framework for the Process
Industry (Final Report)**
WP1 - Water Efficiency Enhancement Applications
Framework and Baseline Assessment

30/09/2024

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ABSTRACT	Deliverable 1.6 is the output of Task 1.5 activities under Work Package 1 of the AquaSPICE project. This deliverable presents the final work of the application of the Water Efficiency Framework (WEF) for the process industry. In this deliverable (D1.6), the framework is applied in Case Study 2 as a demonstration, reported in the intermediary deliverable, D1.7, in detail. D1.6 also reports the application and validation of the WEF to the other Case Studies and the outcomes are reported in a tabular format. In addition to that, a digital maturity model/index has been developed to demonstrate how such tool can be useful, particularly to evaluate and assess the process industry's digital readiness. This is also reported in this deliverable to demonstrate the impact AquaSPICE's digital innovation pillar has had on the Case Studies, measured by the proposed digital maturity model/index. The final WEF is built upon the lessons drawn from the final project period and the feedback from the Case Studies.		

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1. Executive summary

Deliverable 1.6 presents the Water Efficiency Framework (WEF) developed under Task 1.5 of Work Package 1 of the AquaSPICE project. This deliverable demonstrates the application and validation of the WEF across various Case Studies within the process industry. The framework addresses the critical need for a structured approach to enhance industrial water efficiency and circularity, guiding improvements in water management across diverse industry sectors.

The WEF is composed of four phases:

1. **Evaluation of As-Is Situation and Target Setting**
2. **Investigation and Inventory of Opportunities**
3. **Assessment and Expected Outputs**
4. **Policy Development and Dissemination Activities.**

These phases aim to systematically guide industries in improving water use through innovative technologies, process improvements, and strategic planning. The WEF is designed to be flexible and adaptive, allowing it to be tailored to the specific needs of different industrial processes while supporting sustainability goals.

In this Deliverable, the WEF was applied across multiple Case Studies, demonstrating its adaptability and effectiveness. Case Studies from industries such as hydrogen peroxide production, meat production, and the chemical sector have validated the WEF's ability to enhance water efficiency by identifying areas for water reuse, treatment, and recycling. These Case Studies highlight the WEF's broad applicability in reducing freshwater intake, enhancing wastewater reuse, and improving water circularity within industrial processes.

The Case Studies successfully incorporated advanced water treatment technologies such as membrane filtration, UV disinfection, and digital tools like real-time monitoring and water management systems. For example, in the Dow Case Study, the reuse of cooling tower blowdown water significantly reduced freshwater consumption. Meanwhile, in Solvay's peroxide production Case Study, innovative digital sensors optimised the treatment process and enabled wastewater reuse.

A Digital Maturity Index (DMI) was developed to assess the digital readiness of industries in terms of water management. This model helps industries identify areas for technological improvement and prioritise investments in digital solutions. The digital maturity model was successfully applied in the Case Studies, providing insights into how digital technologies can enhance water efficiency.

A significant outcome of is the successful implementation of circular water use strategies in various Case Studies. In the Solvay Case Study, wastewater from peroxide production was treated and reused within the plant, reducing reliance on external water sources. Similar circular approaches were implemented in the BASF and AGRICOLA Case Studies, promoting resource efficiency and sustainability.

The application of the Water Efficiency Framework in the AquaSPICE project highlights its effectiveness in enhancing water efficiency, promoting circular water use, and supporting the digital transformation of water management in the process industry. The results from the Case Studies demonstrate the framework's capability to deliver improvements in water sustainability across various industrial sectors. The WEF, coupled with innovative technologies and policy

recommendations, provides a comprehensive approach to addressing the challenges of industrial water management, making it a valuable tool for industries striving to reduce their water footprint.

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 Figure 1):

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.

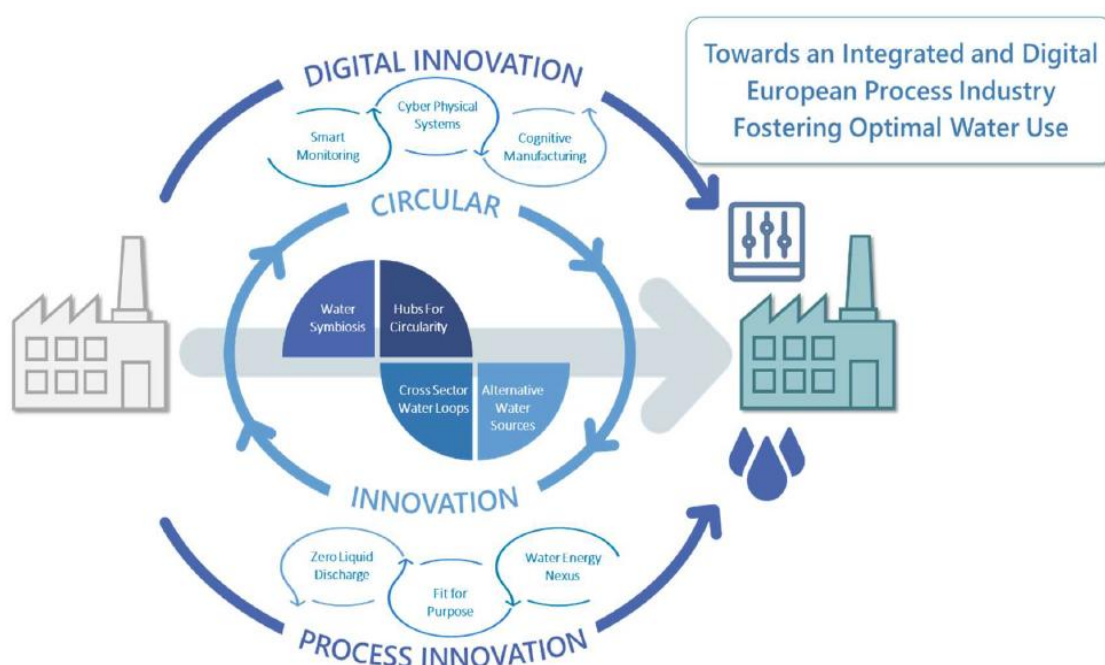


Figure 1– AquaSPICE's 3 pillars towards a water efficient process industry.

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 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 includes 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 1.6 being the application and validation of the previously developed 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 made of 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 use accounts for about 20% of the freshwater resources abstraction and is related to 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.

Freshwater consumption for industrial usage varies significantly between countries. However, this is predicted to increase by a factor of five in developing countries undergoing industrialisation. 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 sewerage system 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 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 Figure 2. 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).

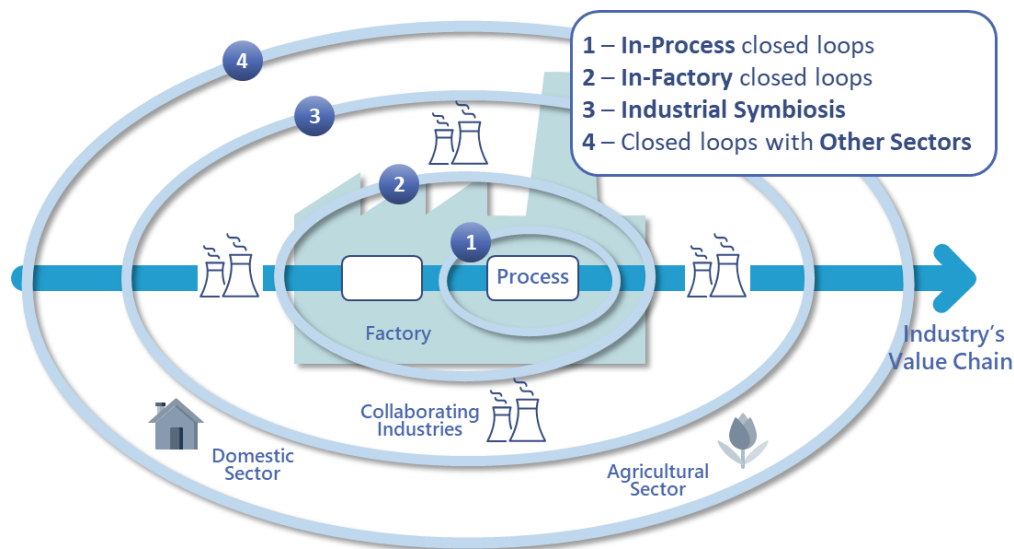


Figure 2– Systemic approach in water management where water efficiency can be achieved in different levels: a single industrial process (unit operation), the entire factory, other collaborating industries (industrial symbiosis) or other sectors (e.g. domestic and/or agriculture)

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], [6], [7], [8], [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 can 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 Figure 3. 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.

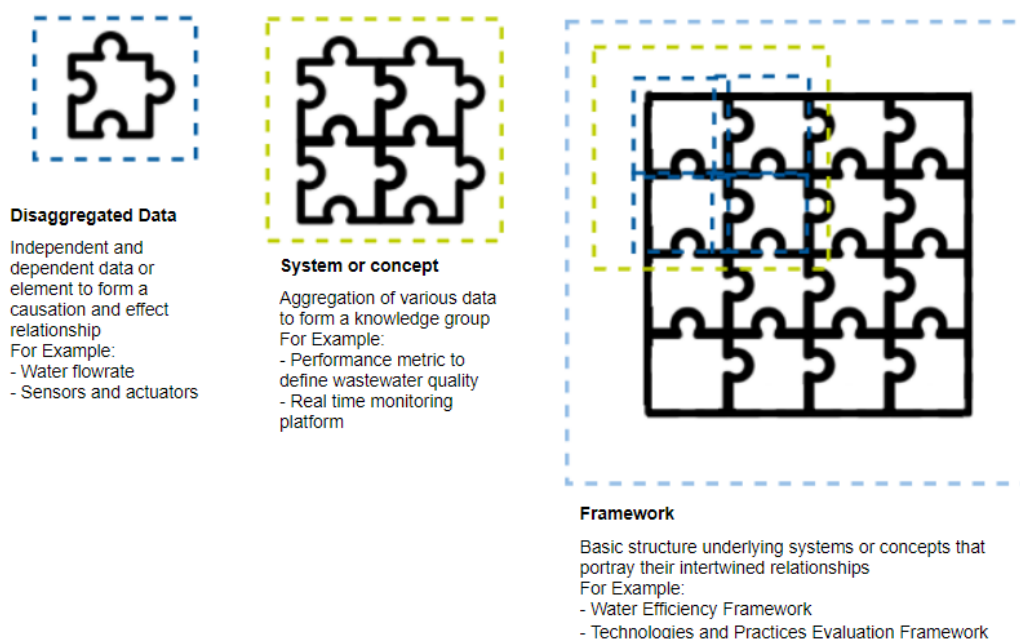


Figure 3– Examples of some building blocks for the industrial WEF

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 Figure 4 below.

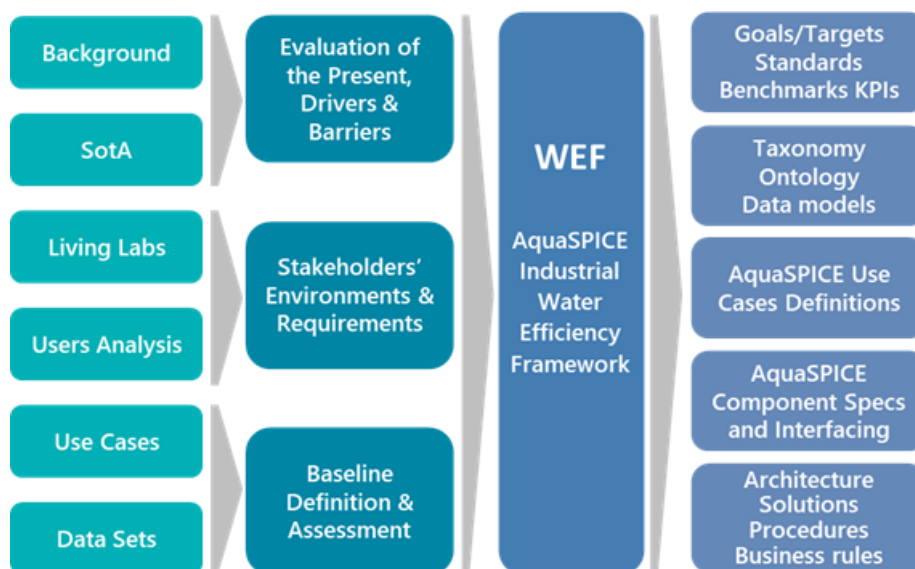


Figure 4– Elements to be included in the WEF

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], [11], [12], [13], [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 Figure 5 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], [17], [18].

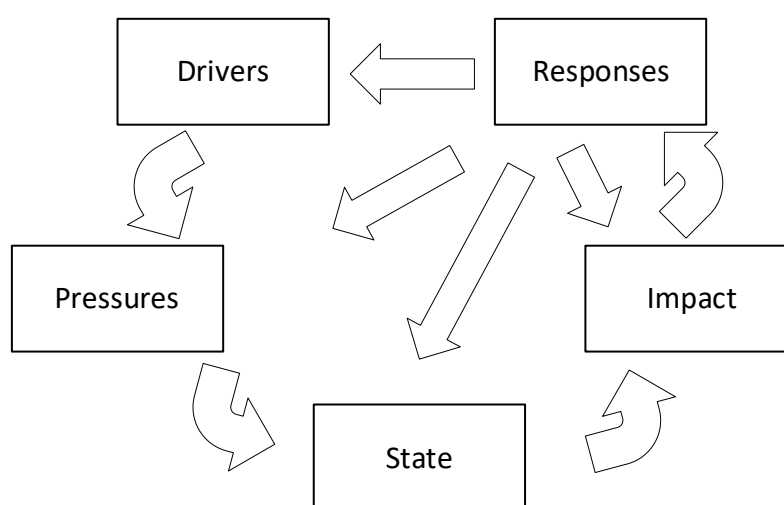


Figure 5–The skeleton of a DPSIR framework (adapted from [15])

4. 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 is demonstrated in the Case Studies and summarised in this final report for WP1, Deliverable 1.6: Water Efficiency Applications Framework for the Process Industry. The AquaSPICE Conceptual Water Efficiency Framework (reported in D 1.5) has been developed in a circular approach and is composed of four phases as shown in Figure 6 below.

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.

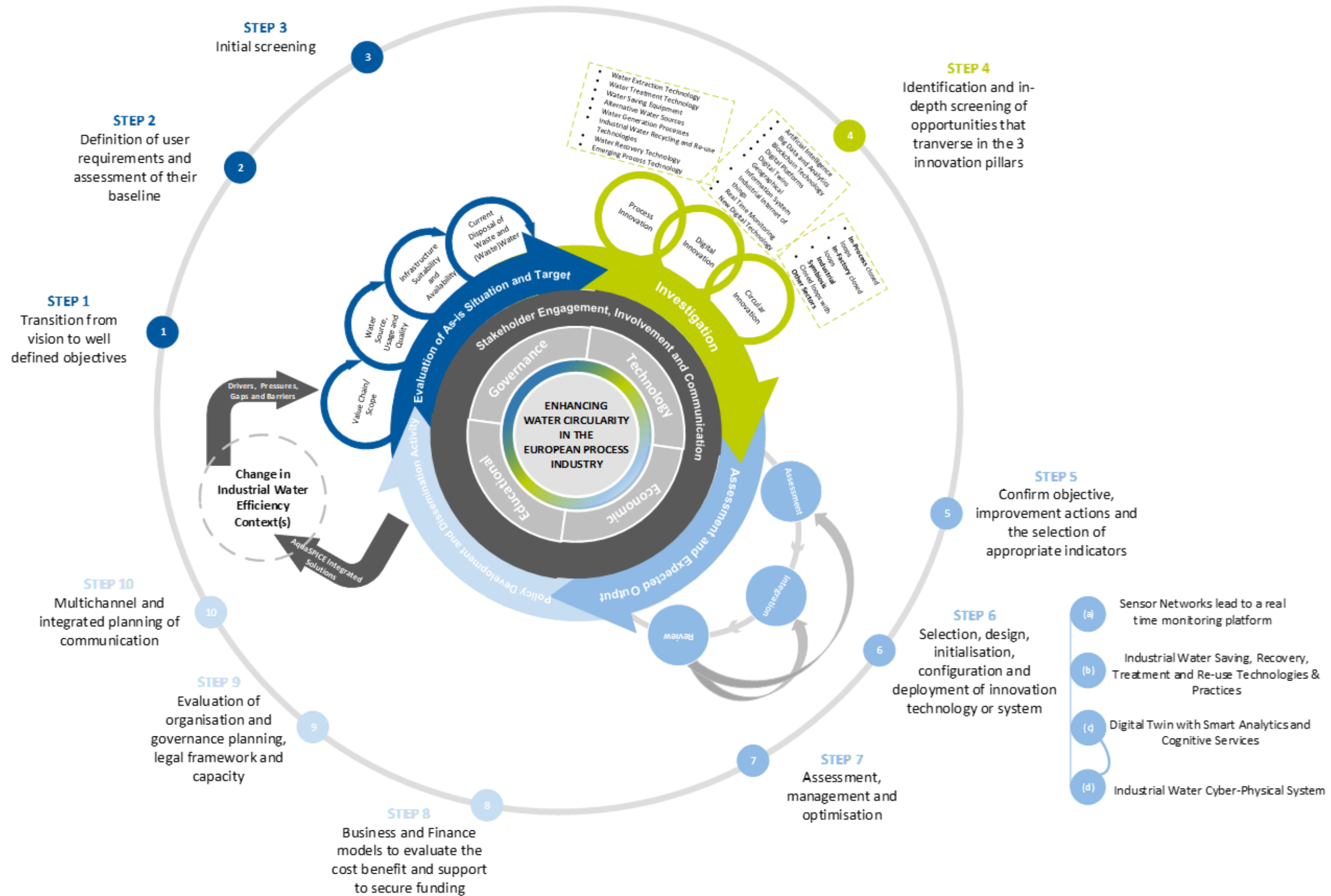


Figure 6– Conceptual Water Efficiency Framework for AquaSPICE

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

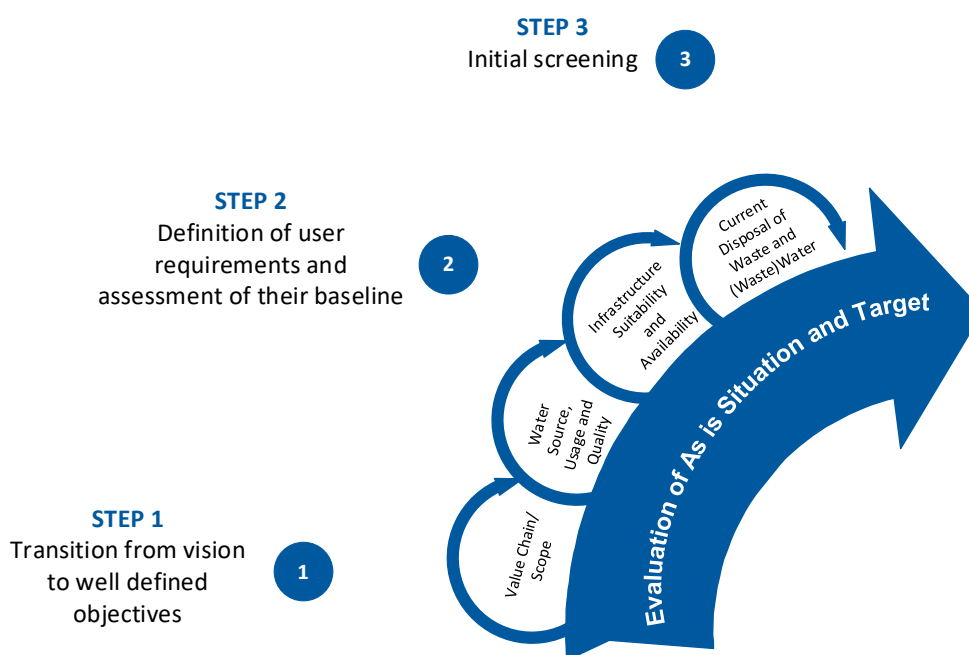


Figure 7– Evaluation of as-is situation and target

4.1.1. 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. To realise this ambitious goal, it is imperative to establish a clear and concise vision that aligns with the objectives of AquaSPICE and prioritises efficient water utilisation within the process industry. While this may present greater challenges in large and complex projects, a well-defined vision serves as a guiding compass, ensuring that efforts remain focused even in the face of increased complexity. It is important to emphasise that AquaSPICE's strategies and tools are applicable to a diverse range of industrial water management initiatives, encompassing both company-wide strategies and more localised site or unit-level projects. By translating the vision into concrete, measurable objectives, we can effectively quantify and evaluate the efficiency of water usage in these endeavors.

4.1.2. 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 initiatives to improve water use in the process industry encompassing both company-wide strategies and more localised site or unit-level projects, 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 Table 1 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.

4.1.3. 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.

4.2. Phase 2: Inventorisation



Figure 8– 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 Figure 8. 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.

4.3. Phase 3: Assessment and Expected Output

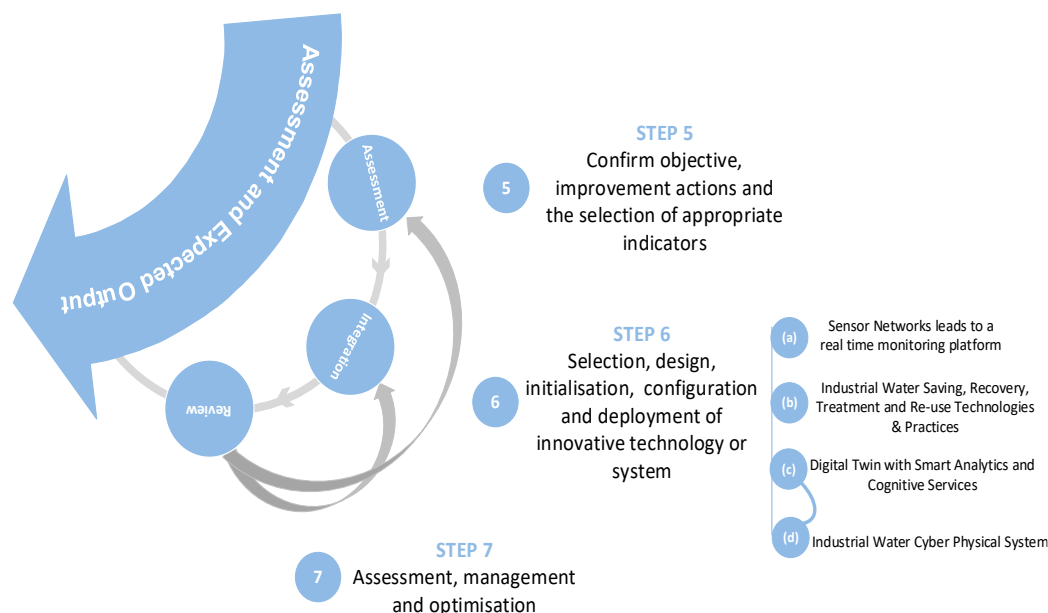


Figure 9– Assessment of AquaSPICE solutions and expected output

4.3.1. 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 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 [19], [20], [21], [22], [23], [24], [25]. An extensive list of more specific indicators can also be generated to ensure the coverage of the broad European process industry category.

4.3.2. 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. Figure 10 shows an example of the ontology for the ULTIMATE project - an H2020 project on water smart industrial symbiosis.

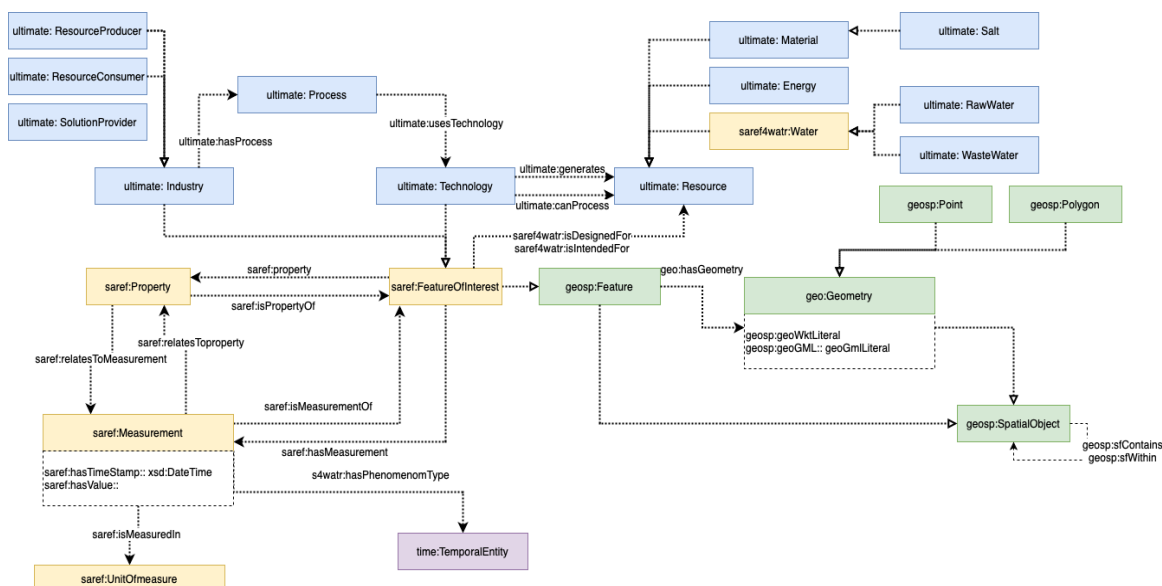


Figure 10— An example of ontology developed for the ULTIMATE H2020 project as the knowledge graph to be shared by individuals who participate in the given domain [26], [27]

4.3.3. 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, for instance, by incorporating holistic modelling concepts, such as dynamic Life Cycle Assessment (LCA). These modelling approaches allow for the quantification and visualisation of optimal and integrated water reuse schemes, including water symbiosis. Through these tools, the project will be able to assess the efficiency and sustainability of water reuse strategies, ensuring a cohesive and comprehensive approach to industrial water management.

The assessment, management and optimisation 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 also be used as a method of assessment, using the common framework of digital maturity models to support, indicate and track the performance 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.

Digital Maturity Models (DMMs) and Technology Readiness Levels (TRLs) can be served as critical tools for evaluating and assessing the process industry's digital readiness and technological advancements in achieving water efficiency. DMMs offer organisations a comprehensive assessment of their current digital capabilities within water management, enabling them to prioritise investments in impactful digital technologies and identify areas for improvement.

On the other hand, TRLs provide a standardised metric for evaluating the maturity of specific water treatment and recycling technologies. This facilitates informed decision-making regarding technology integration and deployment, ensuring resources are directed towards solutions with a high probability of success.

Integrating these models into Phase 3 of the Water Efficiency Framework (WEF) fosters a holistic approach to assessing and elevating water efficiency through digital and technological advancements.

- **Digital Maturity Models (DMMs):** DMMs provide a structured framework for evaluating an organisation's digital capabilities in water management. They assess various aspects, including digital strategy, technology utilisation, data management, and digital culture. This facilitates the identification of strengths and weaknesses for improvement. Conceptualising DMMs as a roadmap for water management digitalisation, highlighting areas where organisations can leverage technology to optimise processes and achieve water efficiency goals. These models typically assess various dimensions such as:

- Strategy: Does the organisation possess a well-defined digital strategy for water management that aligns with overall sustainability goals?
- Technology application: How effectively is the organisation leveraging digital technologies (e.g., real-time monitoring, data analytics, digital twins) to optimise water usage?
- Processes: Are water management processes integrated with digital tools to enhance efficiency and minimise waste?
- Digital culture: Does the organisation foster a culture that embraces digital innovation and continuous improvement in water management practices?
- **Technology Readiness Levels (TRLs):** TRLs offer a standardised metric for assessing the maturity of specific technologies. Developed by NASA, the TRL scale ranges from 1 (basic principles observed) to 9 (fully operational system). TRLs aid in understanding a technology's development stage and planning its integration. TRLs function as a guidepost, allowing organisations to prioritise and select water treatment and recycling technologies that are not only effective but also possess a proven track record of successful implementation. The TRL scale has nine levels, with each level representing a stage in the technology development process:
 - TRL Scale Overview:
 - TRL 1: Basic principles observed.
 - TRL 2: Technology concept formulated.
 - TRL 3: Experimental proof of concept.
 - TRL 4: Technology validated in lab.
 - TRL 5: Technology validated in relevant environment.
 - TRL 6: Technology demonstrated in relevant environment.
 - TRL 7: System prototype demonstration in operational environment.
 - TRL 8: System complete and qualified.
 - TRL 9: Actual system proven in operational environment.

Digital Maturity Models for Water Management in the Process Industries

DMMs can be particularly insightful when used for benchmarking against industry leaders, allowing organisations to identify best practices and expedite their digital transformation journey in water management. This section of the deliverable outlines a Digital Maturity Index (DMI) specifically designed to evaluate the digital preparedness of process industries for achieving water efficiency goals. The DMI synthesises elements from several established digital maturity models, adapting them to the unique needs of water management and is summarised in Table 2 below.

Table 2– Examples of some existing digital maturity framework

Leading Digital Maturity Frameworks	Description
Capability Maturity Model Integration (CMMI) [28]	While primarily used in software development, CMMI's structured approach to assessing organisational capabilities is valuable for evaluating process improvement and maturity in water management.
Gartner's Digital Maturity Model [29]	This model provides a comprehensive view of an organisation's digital readiness by evaluating digital capabilities across five levels, from initiation to optimisation.
Deloitte's Digital Maturity Model [30]	This framework assesses digital maturity across four key dimensions: strategy, culture, technology, and operations. It emphasises the critical integration of digital capabilities with overall business goals.
European Foundation for Quality Management (EFQM) Model [31]	Though focused on quality management, the EFQM model includes dimensions relevant to digital maturity, such as technological integration and process efficiency.

To effectively classify the digital maturity of organisations and processes in the context of water efficiency applications, the following criteria have been established. These criteria span key dimensions such as strategy, technology, processes, people, governance, and stakeholder engagement as shown in Table 3 below, each assessed on a scale from 1 to 4, representing different levels of maturity as detailed in Appendix 8.

Table 3– Adapted elements and criteria from established digital maturity models

Adaptation for Water Efficiency	Description
Strategy and Leadership	
Digital Strategy Alignment	Ensures digital water management initiatives support overall business and sustainability goals (inspired by Gartner and Deloitte).
Leadership Support	Reflects the importance of leadership commitment for successful digital transformation, as emphasised in CMMI and Deloitte's models.
Technology	
Digital Infrastructure	Assesses the robustness and integration of digital infrastructure, including IoT and connectivity, borrowing from Gartner's and EFQM's focus on technological capabilities.

Adaptation for Water Efficiency	Description
Data Management and Analytics	Inspired by Gartner's analytical capabilities focus, this assesses the organisation's ability to effectively manage and utilise data for water efficiency insights.
Processes	
Process Automation	Derived from CMMI's process improvement focus, this criterion evaluates the level of automation within water management processes.
Integration with Operations	Reflecting the integration focus in EFQM and Deloitte's models, this criterion assesses how well digital tools are incorporated into operational water management processes.
People and Culture	
Digital Skills and Competencies	Inspired by Deloitte's emphasis on workforce capabilities, this assesses the availability of skills necessary for supporting digital water management initiatives.
Culture of Innovation	Reflects the cultural dimension of innovation from Deloitte's model, assessing how supportive the organisation is towards digital transformation in water management.
Governance	
Digital Governance Framework	Derived from CMMI and EFQM, this criterion evaluates the presence and effectiveness of governance structures for overseeing digital water management initiatives.
Cybersecurity and Data Privacy	Inspired by the comprehensive risk management focus in Gartner's model, this assesses the measures in place to protect data and ensure security within digital water management systems.
Customer and Stakeholder Engagement	
Stakeholder Involvement	Reflecting the stakeholder engagement emphasis in EFQM and Deloitte's models, this criterion evaluates the extent to which stakeholders are involved in water management digital initiatives.

4.4. Phase 4: Policy Development and Dissemination Activity

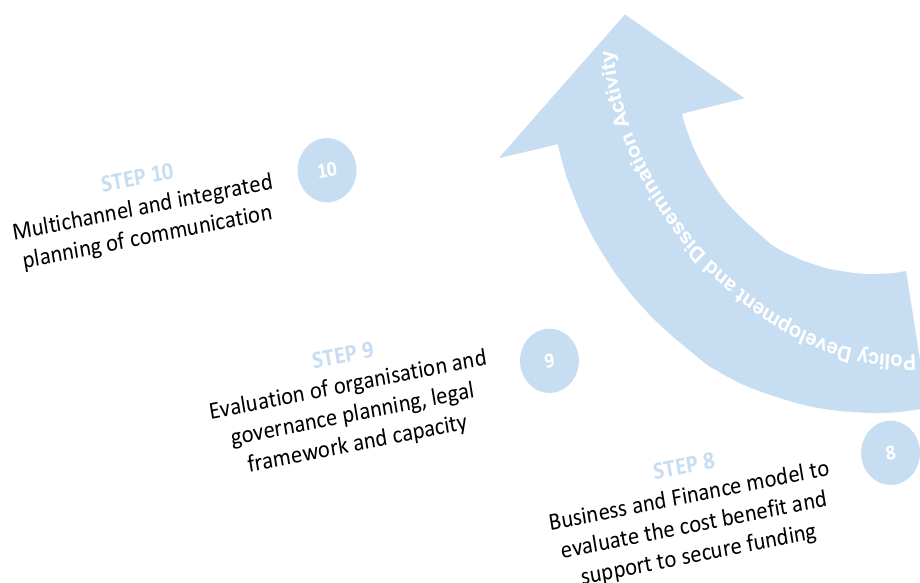


Figure 11– Policy development and dissemination activity

4.4.1. 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.

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

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.

4.4.3. 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.

5. Application of WEF in Case Studies

5.1. Background

AquaSPICE's innovations regarding holistic water management are driven by several business cases in the process industries. As shown in Figure 6, 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.

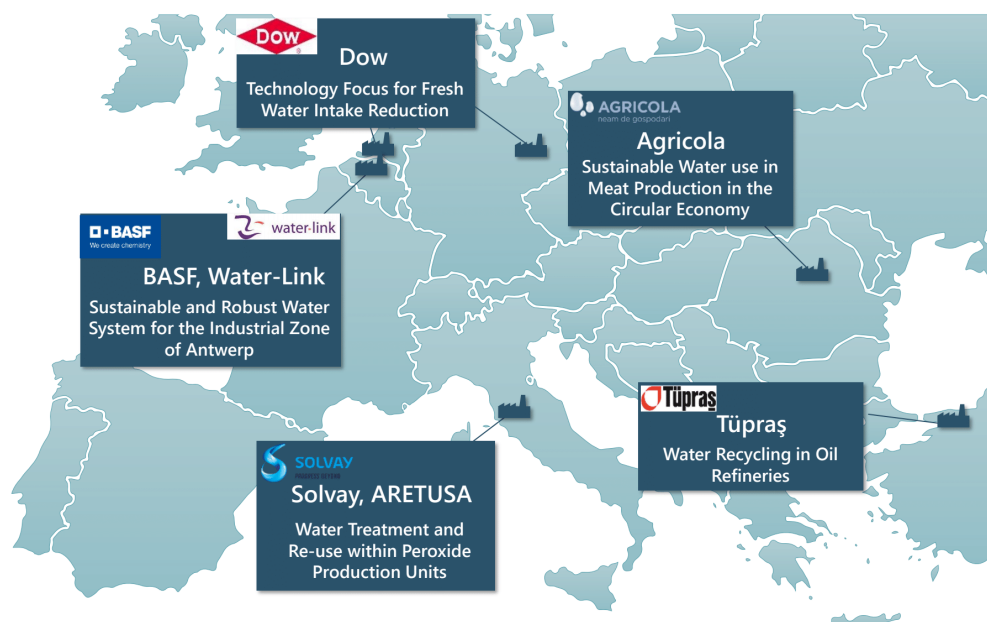


Figure 12– AquaSPICE Case Study locations

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 [32]. 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 [33]. 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 the AquaSPICE project, the Water Efficiency Framework (WEF) was validated across various phases and steps using multiple Case Studies. Case Study #2 was examined in detail, while a summary table synthesises the validation results from the other Case Studies. This comprehensive approach to validation underscores the robustness of the WEF, demonstrating its capacity to guide effective water efficiency practices across diverse contexts.

5.2. Application of the WEF on SOLVAY, Aretusa, Water Treatment and Re-use within Hydrogen Peroxide Production Units

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 **Error! Reference source not found.** 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 transitioned into implementing a water reuse technology for the wastewater of peroxide and peracetic acid production from the Solvay plant

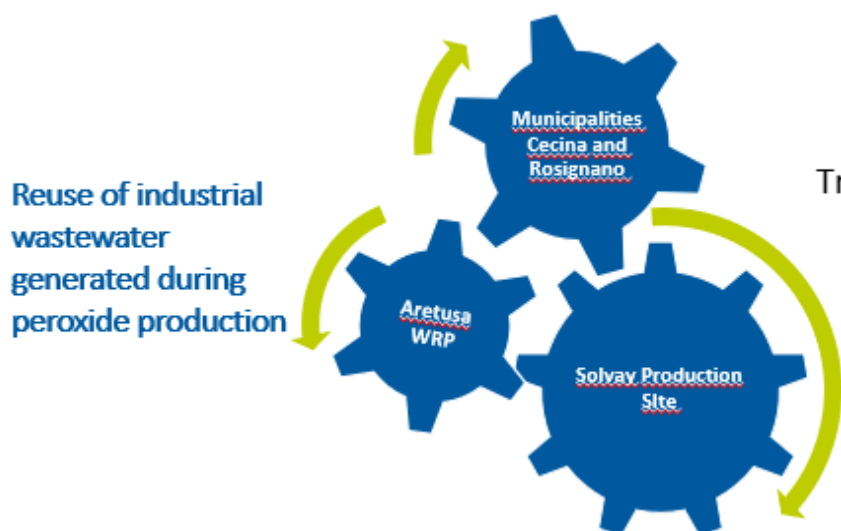


Figure 13– Main actors in Case Study #2

- 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 cooling tower reuse.

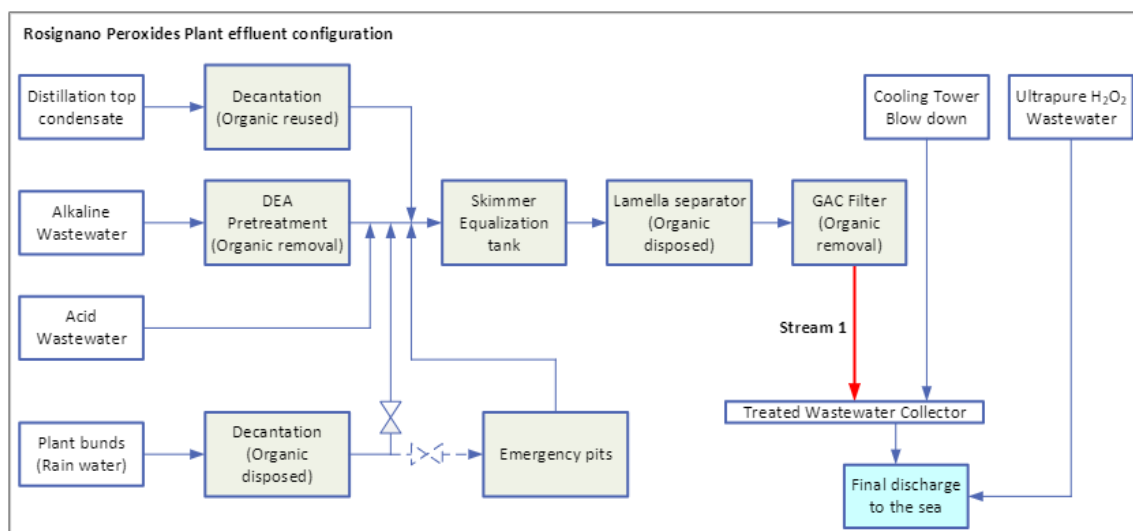


Figure 14– The current scheme of Case Study #2, where stream 1 is treated and discharged into the sea as the baseline (extracted from D1.2).

- 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 at the Solvay plant for the cooling process</u> .

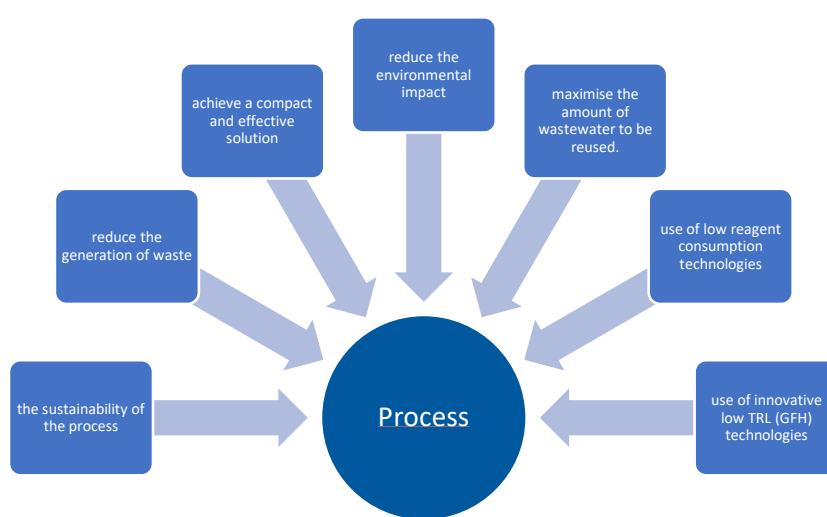
Figure 15– Initial screening of opportunities

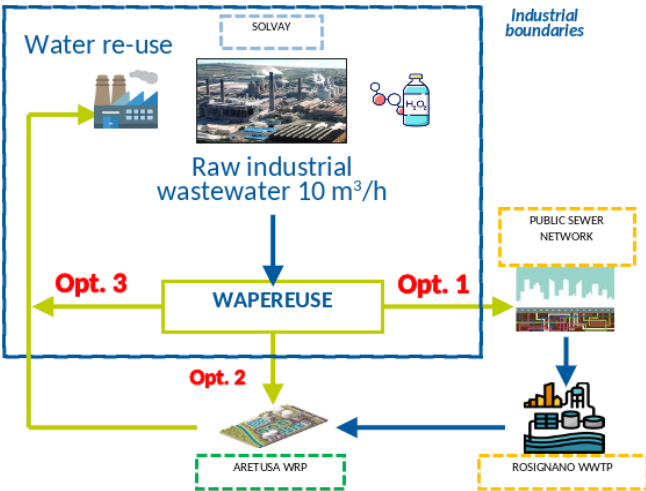
Phase 2: Inventorisation

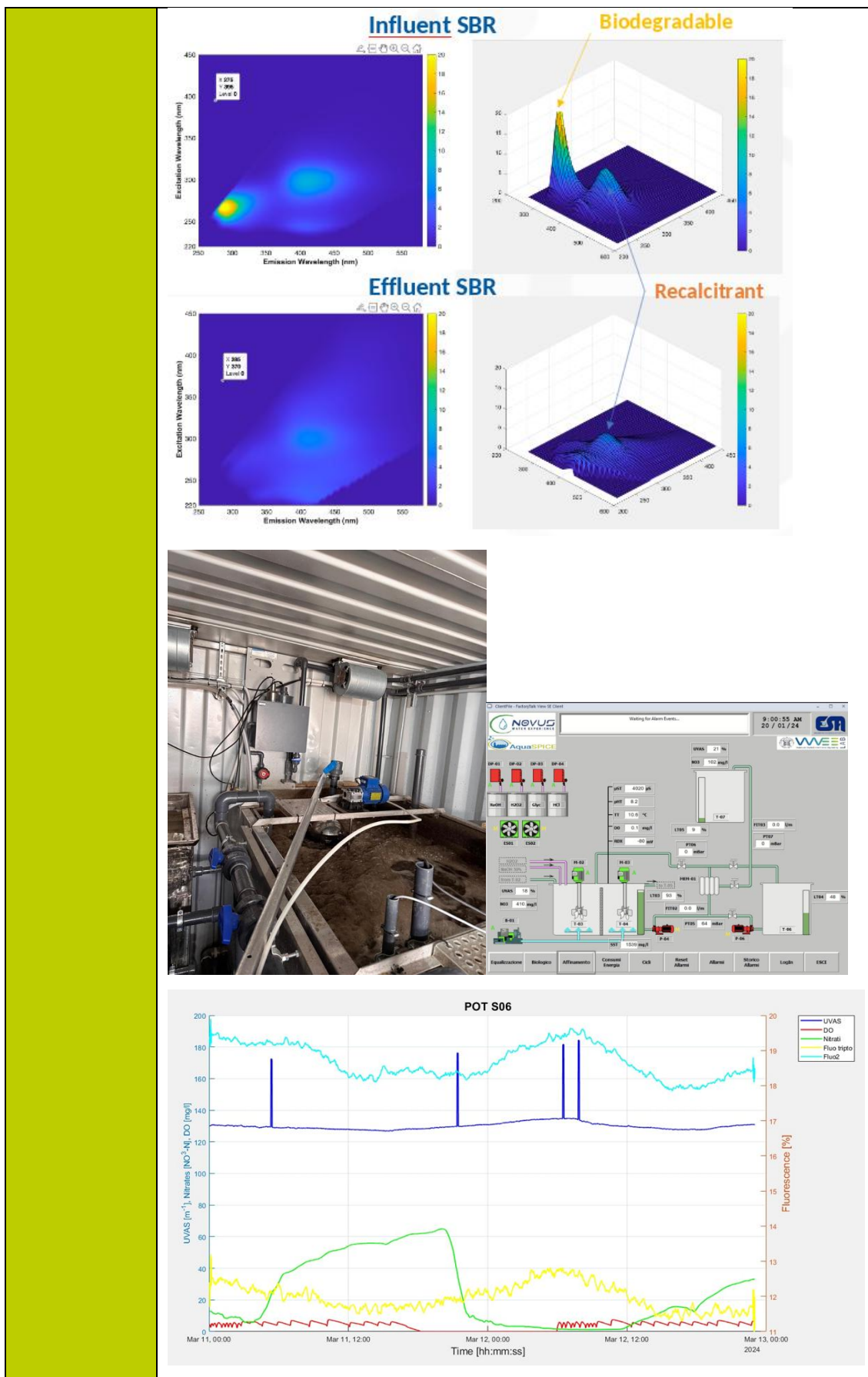
- Step 4: Identification and in-depth screening of opportunities that transverse into the 3 innovation pillars

The Case Study reflects AquaSPICE’s approach to water management that emphasises the importance of efficiency through the adaptation of appropriate technologies and practices. This approach is based on three innovation pillars as elaborated in section 4.2 of the report and demonstrated in Table 4.

Table 4– 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	The design and implementation of innovative processes to reduce waste generation and achieve a compact and effective solution. The use of novel technologies, like membrane filtration and IV spectroscopy, to enhance process efficiency and quality control. 
Circular Innovation	Strategic management of wastewater treated, through multiple circular options

	• The integration of circular economy principles into industrial processes, promoting resource reuse and minimizing waste. • The development of sustainable and recyclable materials and products. • The creation of industrial symbiosis networks to facilitate resource sharing and waste reduction. 
Digital Innovation	The application of spectroscopic sensors (UV absorbance and fluorescence) to understand the progress of the biological process and to automatise the treatment process • The use of digital technologies to optimise processes, improve decision-making, and enhance sustainability. • The implementation of dynamic LCA to assess environmental impacts and identify opportunities for improvement. • The application of digital tools for data collection, analysis, and visualisation.



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.

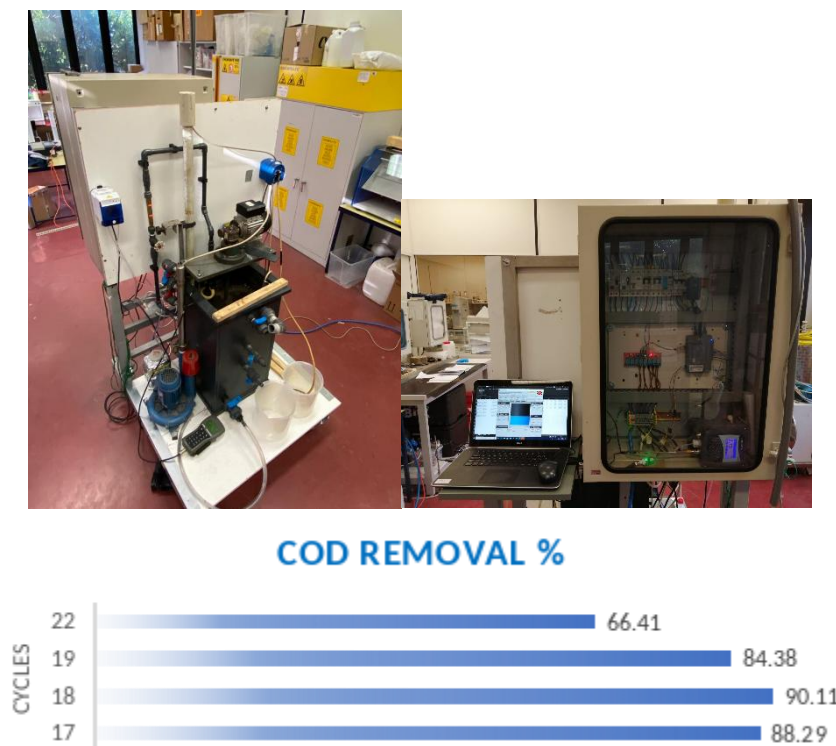


Figure 17– Laboratory study of SBR and COD (key contaminant) removal for Case Study#2 under different process conditions. (figure extracted from AquaSPICE 2023 General Assembly meeting presentation)

After deployment of innovative solutions to treat Solvay wastewater, results were collected to evaluate the effectiveness of treatment at pilot scale.



Figure 18– Demonstration tests accomplished at pilot scale

- Step 7: Assessment, management and optimisation

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 a series of technologies, including a neutralisation tank, an advanced oxidation process (AOP), a membrane bioreactor (MBR) and potentially granular activated carbon for reuse for Case Study #2 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 water technologies. Two alternative scenarios have been formulated for Case Study #2. Scenario 1 corresponds to the existing situation and Scenario 2 corresponds to the wastewater treatment scheme after the implementation of the three AquaSPICE technologies. More information can be found in D4.4 –Water Dynamic Life-Cycle Assessment.

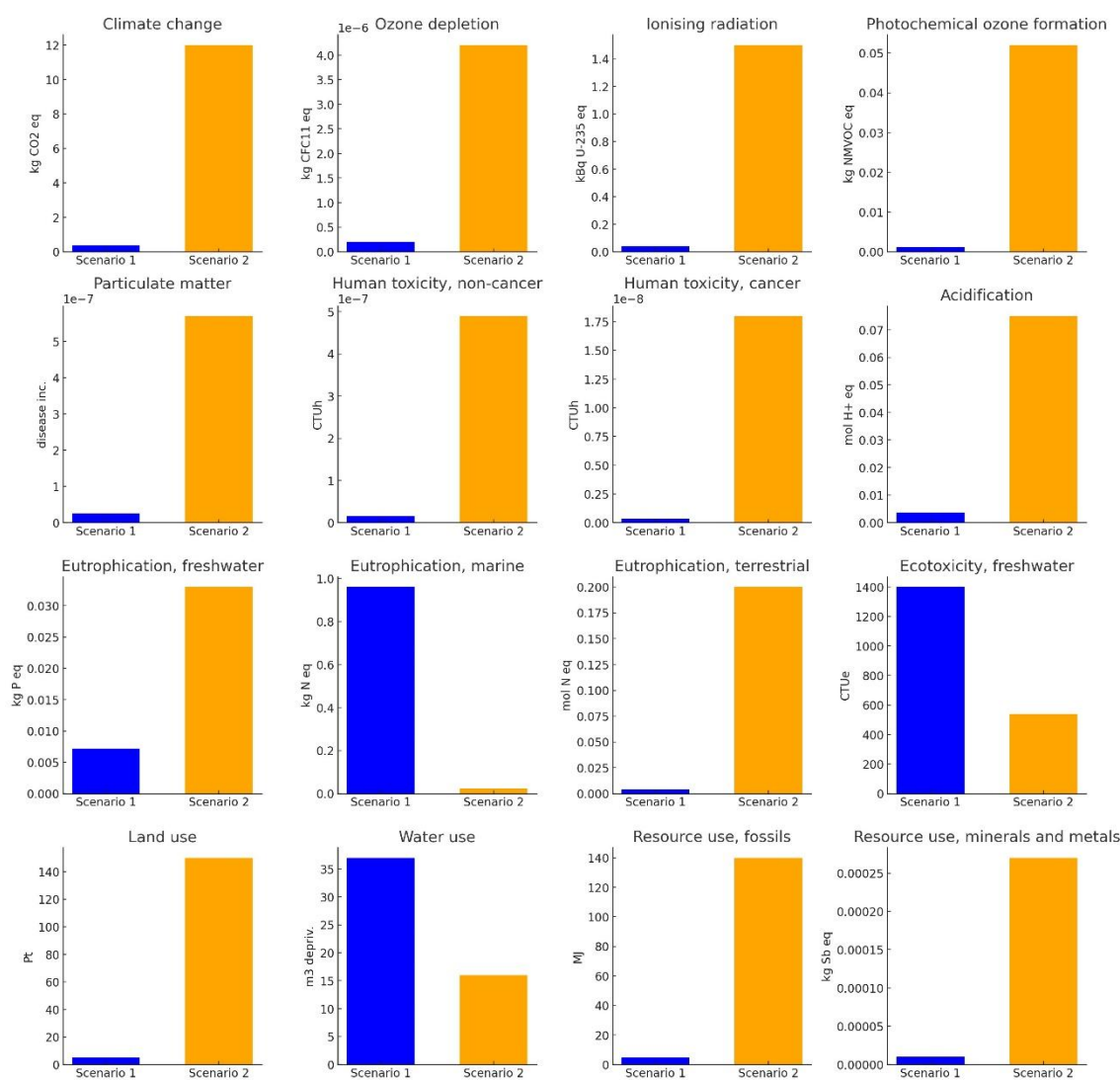


Figure 19–LCA to evaluate the environmental impacts of the water technologies deployed in comparison to the existing situation. The assessment focused on 16 environmental impact categories to identify the trade-offs associated with these new technologies. (Adapted from AquaSPICE Deliverable 4.4)

Phase 4: Policy Development and Dissemination Activity

This phase of the framework aims to develop innovative business models and funding mechanisms to promote industrial water efficiency. Despite the critical role of water in human activities and societies, industrial water management has received limited attention in terms of business models and funding opportunities. By developing evidence-based solutions and effective uptake strategies, this will enable the exploration of new business models and support market creation through a thorough analysis, profiling, and sharing of business models and services for circular water opportunities in the process industry. It is also important to addressing cultural perceptions and implications related to wastewater reuse to encourage water circularity. Thus an effective communication plan to disseminate information to a wider community to maximise its impact were planned. This will involve a knowledge users' analysis to identify relevant companies, disciplines, and technical profiles, as well as building a curriculum to share knowledge and findings.

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

Solvay aims to scale up its wastewater treatment process, including digital technologies, to a full-scale operation. Data from the AquaSPICE project will be crucial for evaluating this potential. Given the global challenges faced by Solvay's Peroxide plants, the replicability of the WAPERUSE treatment system is a key factor. A robust business and financial model is essential for supporting this scaling effort. This model will evaluate the treatment process's cost-benefit, identify cost-reduction opportunities, and enhance benefits. Additionally, it will help secure funding by identifying potential sources and developing strategies for financial support.

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

The successful operation of the WAPERUSE demo plant has validated the potential for treating wastewater to a quality suitable for discharge into the municipal sewer network. Moreover, with further treatment, the treated wastewater can be repurposed for reuse within Solvay's own operations, thereby reducing the company's reliance on external water sources.

The data gathered during the AquaSPICE project can serve as a valuable resource in negotiating new agreements between industrial partners, like Solvay, and public water utilities. These agreements can facilitate the implementation of water reuse initiatives at industrial sites, promoting sustainable water management practices and contributing to environmental conservation. By leveraging the insights gained from the WAPERUSE project and the AquaSPICE data, Solvay can play a pivotal role in driving the adoption of water reuse technologies and fostering a more circular economy.

- Step 10: Multichannel and integrated planning of communication

This Case Study has effectively utilised community of practices and public engagement initiatives to foster collaboration, share knowledge, and obtain valuable feedback from stakeholders. The establishment of two community of practices in conjunction with the ULTIMATE project has facilitated the identification of synergies between the two initiatives. This collaborative approach has strengthened the project's impact and broadened its reach.

Moreover, the project partners of the Case Study have actively participated in conferences and exhibitions, such as WWC2022, EcoSTP2023, ICEEM2023, and ECOMONDO 2022. These platforms have provided opportunities to showcase the project's achievements, engage with a wider audience, and promote the importance of sustainable water management practices.

The organisation of community of practices and Living Lab events has played a crucial role in involving stakeholders and gathering their insights. These initiatives have fostered a sense of ownership and encouraged active participation in the project's development. By actively seeking feedback and incorporating it into the project's direction, AquaSPICE has ensured that it remains aligned with the needs and priorities of its stakeholders.

Through these multichannel and integrated communication efforts, AquaSPICE has effectively disseminated information, built relationships, and fostered a collaborative environment. This approach has not only enhanced the project's visibility but has also contributed to its overall success and sustainability.

5.3. Application of the WEF on all AquaSPICE Case Studies

The application of the WEF was also conducted on all the other AquaSPICE Case Studies. A summary table synthesising the validation results is listed for each Case Study below.

5.3.1. 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 (CTBD) and dilution steam blowdown (DSBD) 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.

The application of the WEF on CS#1 is summarised in Table 5 below.

Table 5– Application of the Water Efficiency Framework on Case Study #1

Water Efficiency Framework	Insights/Learnings from Case Study	Coherence with Water Efficiency Framework
Phase 1: Evaluation of As-is Situation and Target		
Step 1: Transition from vision to well-defined objectives	The focus was on reducing freshwater intake by reusing various streams such as CTBD, DSBD, and slightly polluted WW, and improving raw water treatment. Trials were carried out according to the schedule, and a clear picture emerged on which technology to prefer for future use at both Dow sites.	This step aligns with the framework's goal of defining clear objectives for water efficiency, specifically by targeting freshwater reduction and optimizing water treatment processes.

Water Efficiency Framework	Insights/Learnings from Case Study	Coherence with Water Efficiency Framework
Step 2: Definition of user requirements and assessment of their baseline	Qualitative and quantitative KPIs were defined with input from SMEs, focusing on technology expertise and operational needs.	The initial definition of KPIs and requirements was critical to ensuring the trial's alignment with water efficiency objectives.
Step 3: Initial Screening of approaches, options, and technologies	Initial technology options were screened in a lab environment and promising combinations were tested in the IMPROVED mobile research facility.	The screening process was essential for identifying effective technologies that could enhance water efficiency.
Phase 2: Investigation/ Inventorisation		
Step 4: Identification and in-depth screening of opportunities that transverse into the 3 innovation pillars (process, circular, and digital)	During the pilot phase, ongoing evaluation led to more intensive testing of promising technologies. For Böhlen, reusing CTBD was identified as the most effective way to reduce freshwater intake. Terneuzen faced challenges with DSBD treatment, requiring a complex train of technologies. Digital efforts included the installation of additional meters and analysers to optimise water treatment.	Aligns with the framework's focus on process optimisation, circular water use, and the integration of digital tools to improve water management efficiency.
Phase 3: Assessment and Expected Output		
Step 5: Confirm objectives, improvement actions, and the selection of appropriate indicators (KPIs)	Testing confirmed goals of improving water efficiency and sustainability. Key findings included the need for enhanced pretreatment for water quality, challenges in removing TOC from DSBD, and the stable performance of the GAC-UF-RO train in CTBD treatment.	Supports the continuous assessment of objectives and KPIs to drive innovation and improvements in water management, critical for achieving water efficiency.
Step 6: Selection, design, initialisation, configuration, and deployment of innovative technology or system	Based on the trials, effective technologies were selected and deployed, such as the GAC-UF-RO train for stable performance and significant water savings. The outcomes will influence future project scopes and strategies for water management at both sites.	Directly related to the deployment of technologies that enhance water quality and efficiency, a key aspect of the water efficiency framework.

Water Efficiency Framework	Insights/Learnings from Case Study	Coherence with Water Efficiency Framework
Step 7: Assessment, management, and optimisation of the case study	Ongoing evaluation during trials allowed for adjustments as needed to optimise performance.	Reflects the importance of ongoing management and optimisation, ensuring that water efficiency goals are met throughout the project lifecycle.
Phase 4: Policy Development and Dissemination Activity		
Step 8: Business and Finance model to evaluate the cost-benefit and support to secure funding (Uptake of AS solutions)	A business case is being formulated for Dow to secure funding for defined projects, such as installing a UF unit in the raw water treatment plant in Böhlen.	Highlights the need for a robust business model to support the scalability and sustainability of water efficiency solutions, ensuring long-term impact.
Step 9: Evaluation of organisation and governance planning, legal framework, and capacity	As part of the water strategy, some aspects from AquaSPICE could be shared with authorities, especially regarding discharge permits potentially impacted by new technologies.	Reflects the need to align water efficiency efforts with regulatory requirements and governance structures, ensuring compliance and support for innovations.
Step 10: Multichannel and integrated planning of communication	Results were presented at conferences, workshops, and through various communication channels. Additional publications are in preparation to share findings.	Emphasises the importance of communication and dissemination of knowledge to enhance the broader adoption of water efficiency practices.

5.3.2. 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.

The application of WEF on CS#2 is summarised in Table 6

Table 6– Applications of Water Efficiency Framework on Case Study #2

Water Efficiency Framework	Insights/Learnings from Case Study	Coherence with Water Efficiency Framework
Phase 1: Evaluation of As-is Situation and Target		
Step 1: Transition from vision to well-defined objectives	The roles of partners involved in the case study (industrial symbiosis) are clarified. Waste management strategies and reuse limits were defined according to strategic objectives and company policy (Solvay One Planet).	Aligns with the framework's goal of setting clear objectives and understanding stakeholder roles to ensure that water reuse limits and KPIs are defined according to strategic goals.
Step 2: Definition of user requirements and assessment of their baseline	Solvay provided data on peroxide production wastewater treatment, allowing a better understanding of the main contaminants and the critical parameters for focused treatment. This was key to defining the requirements for the treatment process.	Supports the establishment of a clear baseline by understanding the contaminants and necessary treatment parameters, essential for achieving water treatment and reuse efficiency.

Water Efficiency Framework	Insights/Learnings from Case Study	Coherence with Water Efficiency Framework
Step 3: Initial Screening of approaches, options, and technologies	The treatment stream was defined based on analytical measurements of wastewater quality. The reuse option within Solvay's industrial boundaries was revised based on this data.	Directly related to identifying and refining effective treatment options, crucial for enhancing water quality and enabling reuse within the industrial site.
Phase 2: Investigation/Inventorisation		
Step 4: Identification and in-depth screening of opportunities that transverse into the 3 innovation pillars (process, circular, and digital)	The design and operation of the pilot focused on sustainability, reducing waste, achieving a compact and effective solution, and maximising wastewater reuse. Strategic management through circular options was achieved with stakeholders. Digital sensors automated the treatment process, optimising costs and environmental impacts.	Aligns with the framework's focus on process optimisation, circular water use, and the integration of digital tools to improve water management efficiency.
Phase 3: Assessment and Expected Output		
Step 5: Confirm objectives, improvement actions, and the selection of appropriate indicators (KPIs)	The pilot plant's operation confirmed the possibility of reaching objectives and KPIs, with treated wastewater quality suitable for reuse or discharge into the sewer network. This aligns with Solvay's sustainability goals under the Solvay One Planet initiative.	Supports the continuous assessment of objectives and KPIs, ensuring that the project's goals align with broader sustainability and water efficiency targets.
Step 6: Selection, design, initialization, configuration, and deployment of innovative technology or system	A demo plant equipped with innovative sensors was successfully operated to treat industrial wastewater. Online data was collected for automation and optimisation, and real-time data was fed into a predictive platform developed under AquaSPICE.	Directly related to the deployment of technologies that enhance water quality and efficiency, a key aspect of the water efficiency framework.
Step 7: Assessment, management, and	The WAPERUSE pilot system was operated to treat industrial wastewater at the Solvay site, with	Reflects the importance of ongoing management and optimisation, ensuring that

Water Efficiency Framework	Insights/Learnings from Case Study	Coherence with Water Efficiency Framework
optimisation of the Case Study (i.e. Solvay)	real-time data used for optimisation. Laboratory measurements validated the reliability of collected sensor data. The demo plant operations showed the possibility to reach these limits, particularly for discharging into municipal sewer networks.	water efficiency goals are met throughout the project lifecycle.
Phase 4: Policy Development and Dissemination Activity		
Step 8: Business and Finance model to evaluate the cost-benefit and support to secure funding (Uptake of AS solutions)	Solvay is highly interested in the treatment process and its digital technologies. Data from the pilot will be used to evaluate possible scaling to full-scale operations, with replicability at other Solvay sites considered.	Highlights the need for a robust business model to support scalability and sustainability of water efficiency solutions, ensuring long-term impact.
Step 9: Evaluation of organisation and governance planning, legal framework, and capacity	The demo plant operation showed the possibility to treat wastewater to a quality suitable for discharge, supporting potential agreements between industrial and public partners to promote water reuse.	Reflects the need to align water efficiency efforts with regulatory requirements and governance structures, ensuring compliance and support for innovations.
Step 10: Multichannel and integrated planning of communication	Community of Practices and Living Lab events were organised to involve stakeholders and obtain feedback. The AquaSPICE project and its results were presented at conferences (WWC2022, EcoSTP2023, ICEEM 2023) and exhibitions (ECOMONDO 2022).	Emphasises the importance of communication and dissemination of knowledge to enhance the broader adoption of water efficiency practices.

5.3.3. 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 demineralised 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 demineralised 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.

The application of WEF on CS#3 (Albert Canal) is summarised in Table 7.

Table 7– Applications of Water Efficiency Framework on Case Study #3

Water Efficiency Framework	Insights/Learnings from Case Study	Coherence with Water Efficiency Framework
Phase 1: Evaluation of As-is Situation and Target		
Step 1: Transition from vision to well-defined objectives	Discussions between VITO, water-link, and stakeholders helped identify key water streams, current conditions, and technical constraints. This clarified the monitoring network scope and the operational model, which set clear goals and required data analysis.	Aligns with the need to set clear objectives and goals in water management projects by involving stakeholders and addressing real-time needs.
Step 2: Definition of user requirements and assessment of their baseline	Real-time data collection was critical as prior monitoring was primarily based on grab sampling, which failed to capture the dynamic behavior of water streams. The project identified the necessity of continuous monitoring to support decision-making processes related to water intake and pumping activities.	Establishing a baseline for real-time monitoring is fundamental to continuously improve water management practices, moving beyond static data collection methods.
Step 3: Initial Screening of approaches, options, and technologies	The monitoring network and sensors were selected and deployed based on user needs. Factors like robustness, outdoor use, and real-time data transmission were prioritised, and practical constraints like safety and maintenance were considered.	Supports the goal of applying the most appropriate technology and ensuring operational scalability, critical for efficient water management frameworks.
Phase 2: Investigation/Inventorisation		
Step 4: Identification and in-depth screening of opportunities that	This subcase focused on digital aspects through real-time monitoring (sensors, dashboards,	Strong alignment with the framework's digital pillar, as real-time monitoring is a

Water Efficiency Framework	Insights/Learnings from Case Study	Coherence with Water Efficiency Framework
transverse into the 3 innovation pillars (process, circular, and digital)	and data analysis), which provides insights into the water system dynamics and supports climate adaptation strategies.	key innovation for improving water management and ensuring sustainability in the face of climate challenges.
Phase 3: Assessment and Expected Output		
Step 5: Confirm objectives, improvement actions, and the selection of appropriate indicators (KPIs)	Continuous revisions of solutions and sensor networks ensured the collection of high-quality data. The sensors were regularly maintained, and further optimisation measures were implemented after a 1.5-year operational period to improve data quality and sensor performance.	Highlights the importance of revisiting and refining solutions over time to ensure long-term water efficiency and data integrity in operational models.
Step 6: Selection, design, initialization, configuration, and deployment of innovative technology or system	Instrumentation and sensor networks were successfully designed, deployed, and continuously collected data throughout the project. The operational model and dashboards provided ongoing insights for both daily operations and climate-related events.	Aligns with the goal of integrating advanced technology to optimize water use and efficiency, particularly through real-time data collection and scenario modelling.
Step 7: Assessment, management, and optimisation of the case study	As commented in step 5, the case study has been continuously evaluated to provide improvements when needed.	
Phase 4: Policy Development and Dissemination Activity		
Step 8: Business and Finance model to evaluate the cost-benefit and support to secure funding (Uptake of AS solutions)	The monitoring network was designed for future use by different actors, with plans for expansion to other regions. Discussions are underway with stakeholders to develop a collaborative business model.	Addresses long-term scalability and the creation of sustainable business models for the adoption and extension of water efficiency practices, a key component of the framework.
Step 9: Evaluation of organisation and	Efforts continue to develop agreements between stakeholders	Demonstrates the need for continuous organizational

Water Efficiency Framework	Insights/Learnings from Case Study	Coherence with Water Efficiency Framework
governance planning, legal framework, and capacity	to maintain and operate the monitoring network beyond the project's completion.	and governance planning to support water efficiency efforts at a larger scale, ensuring proper governance and capacity building.
Step 10: Multichannel and integrated planning of communication	Communication and dissemination efforts have been robust, with findings presented at international conferences and in journal publications. - 7th YWP BeNeLux conference (2021) - IWA World Water Congress & Exhibition (2022, 2024) - 13th IWA Conference on Instrumentation, Control and Automation (2022) - 11th IWA Symposium on Modelling and Integrated Assessment – Watermatex (2023) The Case Study has also been presented as reference in different international projects (e.g. Darrow, WaterFRAME) and international delegations (eg. UNIDO). These activities will continue during and after the project to disseminated further the positive and added value of the solutions to improve water management and decision making. The monitoring network is also referenced in other international projects.	Strong alignment with the need for transparent communication and knowledge sharing to promote water efficiency practices across sectors and regions.

5.3.4. 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.

5.3.5. 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 optimise 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.

The application of WEF on CS#5 is summarised in Table 8.

Table 8- Applications of Water Efficiency Framework on Case Study #5

Water Efficiency Framework	Insights/Learnings from Case Study #5	Coherence with Water Efficiency Framework
Phase 1: Evaluation of As-is Situation and Target		
Step 1: Transition from vision to well-defined objectives	The vision of becoming the pioneering food industry in Romania for circular water led to the assessment of water balance, legislative specifications, and the identification of reuse opportunities. The project added a new dimension to the	Aligns with the framework's goal of defining clear objectives and exploring reuse opportunities, crucial for circular water

Water Efficiency Framework	Insights/Learnings from Case Study #5	Coherence with Water Efficiency Framework
	company's strategy, with the potential for expansion if subsidies are available.	management and efficiency.
Step 2: Definition of user requirements and assessment of their baseline	The pilot plant aimed to improve effluent treatment quality using advanced technology. The project provided the necessary methodology and knowledge for this assessment, although future upscaling requires support from additional stakeholders. This is particularly crucial in the food industry such as Agricola, where stringent EU regulations mandate the highest standards of drinking water quality.	Supports the establishment of clear requirements and baseline assessments, key to improving water treatment and enabling future scalability.
Step 3: Initial Screening of approaches, options, and technologies	A sampling campaign characterised the pretreated effluent to identify appropriate treatment technologies. The project modernised the previous water sampling methodology, involving the Environmental Department of Agricola more directly in managing water quality risks and reducing public sewage discharge.	Directly related to identifying effective treatment options, crucial for enhancing water quality and efficiency. The updated methodology ensures more accurate assessments.
Phase 2: Investigation/Inventorisation		
Step 4: Identification and in-depth screening of opportunities that transverse into the 3 innovation pillars (process, circular, and digital)	The process aimed to achieve safe water reuse within the slaughterhouse, reduce freshwater consumption, and minimise environmental impact. Digital strategies included implementing real-time bacteria sensors, although the current WWTP's outdated technology requires updates for full integration.	Directly aligned with improving water reuse, reducing consumption, and integrating digital monitoring systems, which are key objectives of water efficiency.
Phase 3: Assessment and Expected Output		
Step 5: Confirm objectives, improvement actions, and the selection of appropriate indicators (KPIs)	Pretreated water characterisation with MBR-UV treatment indicated that KPIs could be met, but achieving initial KPIs requires further evaluation. A potential roadmap by External expert could guide Agricola in reaching these goals.	Highlights the importance of ongoing evaluation and adjustment to meet water efficiency goals.

Water Efficiency Framework	Insights/Learnings from Case Study #5	Coherence with Water Efficiency Framework
Step 6: Selection, design, initialization, configuration, and deployment of innovative technology or system	After sampling and characterisation, a combination of MBR-UV was deployed. Further parameter redesign may be necessary based on measurements to optimise the system.	Supports the selection and deployment of effective treatment technologies, essential for optimizing water quality and achieving efficiency targets.
Step 7: Assessment, management, and optimisation of the Case Study	The plant was commissioned, and an LCA was conducted to assess the environmental impact. An online dashboard was created for real-time visualization of plant data to facilitate optimisation.	Reflects ongoing efforts in optimizing water treatment systems and assessing environmental impact, which are crucial for water efficiency.
Phase 4: Policy Development and Dissemination Activity		
Step 8: Business and Finance model to evaluate the cost-benefit and support to secure funding (Uptake of AS solutions)	The circular water and digital transition are still in the learning phase for Agricola and the region. More needs to be done to develop a business model and seek funding. The investment in a new facility is required, though market conditions and legislation currently pose challenges.	Highlights the need for a sustainable business model and funding support, essential for the long-term viability and scalability of water efficiency solutions.
Step 9: Evaluation of organisation and governance planning, legal framework, and capacity	A CoP was established, holding meetings with key water stakeholders to raise awareness and plan the legal framework for circular water. Further regional collaboration is possible, supported by subsidies and local companies.	Reflects the need for robust organisational and governance structures to support water efficiency initiatives and broader regional collaboration.
Step 10: Multichannel and integrated planning of communication	Several seminars, webinars, and workshops were organised to promote the project. Continuous communication and learning opportunities are encouraged, potentially leading to a Water Operated Living Lab in the region.	Emphasises the importance of communication and knowledge sharing for the successful implementation and dissemination of water efficiency practices.

5.3.6. 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.

The application of WEF on CS#6 is summarised in Table 9.

Table 9- Applications of Water Efficiency Framework on Case Study #6

Water Efficiency Framework	Insights/Learnings from Case Study (Combined and Distilled)	Coherence with Water Efficiency Framework
Phase 1: Evaluation of As-is Situation and Target		
Step 1: Transition from vision to well-defined objectives	The wastewater analytical characterization was crucial for defining realistic objectives and project KPIs. Challenges with water quality variability and need for extensive analytical results for better granulation performance complicated timely responses in the biological reactor.	Directly aligns with the need to set clear, realistic targets and address data quality and timeliness, which are essential for effective water management and efficiency.
Step 2: Definition of user requirements and assessment of their baseline	Initial wastewater sampling provided updated data for the Case Study. Extensive quality analysis of wastewater was conducted in the refinery accredited laboratory. For	Aligns with the need to establish a clear baseline and the importance of real-time data for continuous monitoring and

Water Efficiency Framework	Insights/Learnings from Case Study (Combined and Distilled)	Coherence with Water Efficiency Framework
	continuous operation of the plant, critical analysers for determination of blending and treated wastewater quality were selected and purchased.	improvement in water management efficiency.
Step 3: Initial Screening of approaches, options, and technologies	Technologies were identified, but discussions arose on whether to treat the blending of inlet streams or the outlet stream. One of the valuable insights from the initial screening of approaches is to select a robust and resilient technology for dynamic and challenging characteristics of the refinery wastewater. Two challenging wastewater streams are selected to be treated in granular activated sludge and advanced treatment systems (UF and RO) to be reused for specific purposes (firefighting water, cooling water, etc).	Supports the identification and selection of the most effective water treatment methods, a key aspect of improving water efficiency. The challenges noted highlight areas for improvement in real-time monitoring and control.
Phase 2: Investigation/ Inventorisation		
Step 4: Identification and in-depth screening of opportunities that transverse into the 3 innovation pillars (process, circular, and digital)	The process focuses on sustainability, maximizing wastewater reuse, and effective monitoring through sensors and analysers. Treatment efficiency of granular activated sludge process was tested in this case study. Results of treatment efficiency of pollution parameters are promising for more resilient and robust process technology. Together with digital tools, blending optimisation can be a solution for treating main refinery ww streams which can provide opportunity of the use of alternative and more efficient wastewater treatment technologies.	Directly related to maximizing water reuse and improving monitoring, key objectives of a water efficiency framework. The lack of sensor data points to areas needing enhancement.
Phase 3: Assessment and Expected Output		

Water Efficiency Framework	Insights/Learnings from Case Study (Combined and Distilled)	Coherence with Water Efficiency Framework
Step 5: Confirm objectives, improvement actions, and the selection of appropriate indicators (KPIs)	The pilot plant operation phase is progressing. Daily analytical data, online monitoring system, determination of optimum operation conditions are crucial for managing continuous operations. Operation period of pilot plant can be one of the KPIs for evaluating performance.	Highlights the importance of ongoing assessment and adjustment to meet water efficiency goals. The identified issues are critical to address for improving operational efficiency and water management.
Step 6: Selection, design, initialization, configuration, and deployment of innovative technology or system	Initial sampling and lab work were critical for the pilot's design. Some key insights during operation were observed. The reactor performance was affected by miswritten logic, and granulation trials were also affected from pH adjustment requirement. Selection, design and configuration of technology should be done according to variations of wastewater characteristics. Fast responses to changing situations are crucial for continuous operations. Such an innovative technology should be introduced to users by experts.	Supports the selection and deployment of technology, key to optimizing water efficiency. However, design and operational challenges highlight areas where the framework's objectives are not fully met yet.
Phase 4: Policy Development and Dissemination Activity		
Step 7: Assessment, management, and optimisation of the case study	The pilot plant was installed and began operations in November 2023. Field trials and reinoculation of granular activated sludge trials has been conducted. During trials efficient removal has been approached. More trials provide better understanding of system and granulation process. During trials optimum conditions such as pH, blending ratio are understood.	Reflects ongoing efforts in optimizing water treatment systems, essential for achieving water efficiency.
Step 8: Business and Finance model to evaluate the cost-benefit and support to	There is no immediate intention to scale up the solution, but future investments may consider replicability	Addresses the long-term sustainability and scalability of water efficiency solutions, which is vital for broader

Water Efficiency Framework	Insights/Learnings from Case Study (Combined and Distilled)	Coherence with Water Efficiency Framework
secure funding (Uptake of AS solutions)	at other Tüpras plants. Feasibility study should be applied.	application of the framework across multiple sites.
Step 9: Evaluation of organisation and governance planning, legal framework, and capacity	Technology of pilot plant can contribute to Tüpraş's and other refineries' aim to sustain water circularity and near zero discharge for sustainability targets.	Demonstrates the need for continuous organizational and governance planning to support water efficiency practices company-wide.
Step 10: Multichannel and integrated planning of communication	Project results are expected to be shared with Tüpraş refineries and in knowledge sharing platforms.	Highlights the importance of communication and knowledge sharing for broader implementation of water efficiency practices.

5.4. Using Digital Maturity Models to Support the Assessment of the Framework

As described in Table 3 above, a digital maturity model can be a comprehensive framework designed to assess an organisation's readiness and capability to harness digital technologies for achieving strategic goals. Its application on AquaSPICE's Case Studies can be summarised in below section.

Case Study #1 indicates that the AquaSPICE initiative has contributed to some improvements in certain areas of digital maturity at the Dow sites in Böhlen and Terneuzen as shown in Figure 20. Notably, the Digital Strategy Alignment has improved from a score of 3 to 4, largely due to the installation of flow measurements that close data gaps and enhance system automation. Additionally, there has been a positive shift in the Culture of Innovation, moving from 3 to 4, driven by the efforts of the Global Digital Operations Center (DOC), which is leading the charge in integrating emerging technologies to improve various aspects of manufacturing.

Other areas such as Leadership Support, Digital Skills and Competencies, Cybersecurity, and Data Privacy remain strong, maintaining high scores of 4, indicating that these elements were already well-established before AquaSPICE and have continued to be robust. However, improvements in Digital Governance Framework and Stakeholder Involvement are noted, both rising from 2 and 3 to 3 and 4 respectively, showing a clearer structure and enhanced involvement in digital projects. Overall, while significant gains were made in some areas, others have remained consistent, reflecting the existing strength in Dow's digital infrastructure and governance.

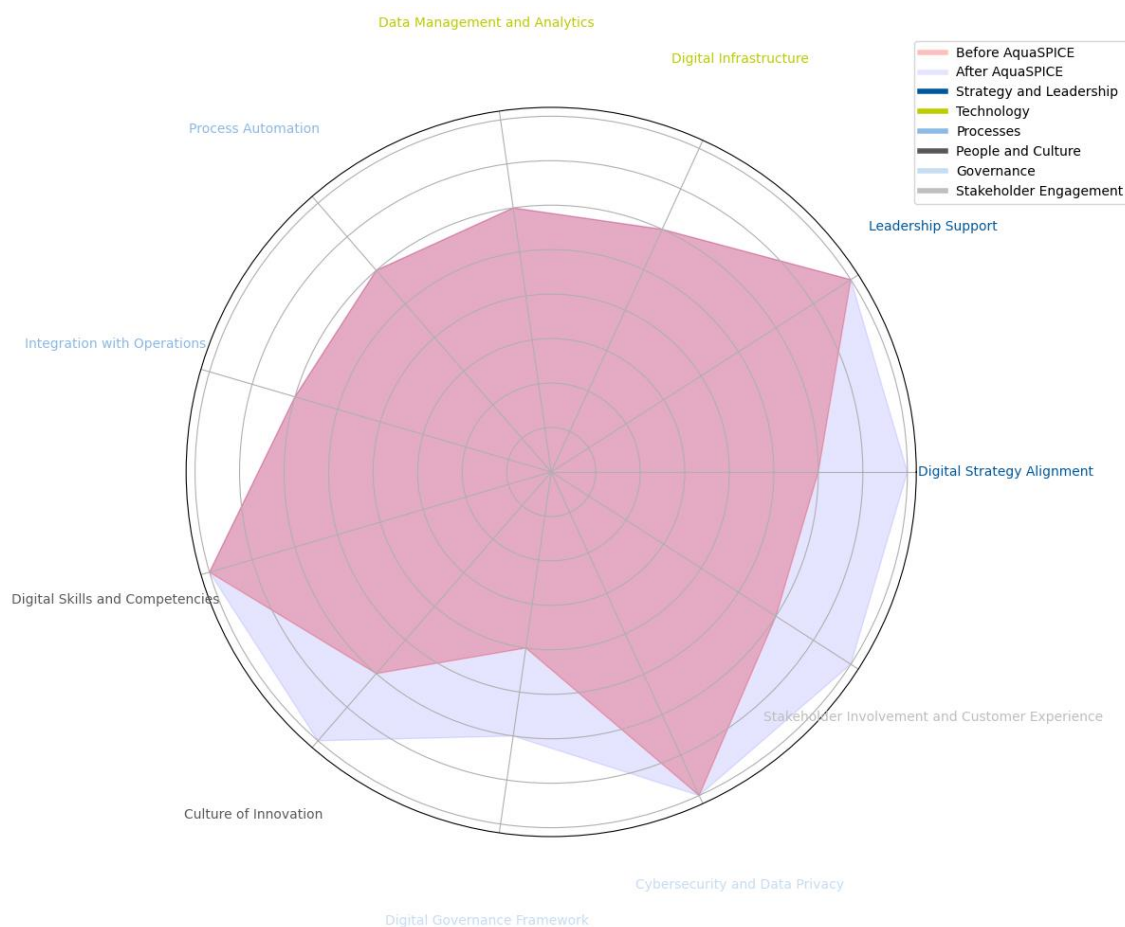


Figure 20- Digital Maturity Assessment for Case Study #1

For CS#2, the AquaSPICE project has significantly advanced the digital maturity of Solvay's wastewater treatment operations, shown in Figure 21 below. Before the project, there was minimal alignment between digital strategies and operational processes, with limited leadership support and digital infrastructure. However, the project successfully implemented new digital tools and strategies, particularly in automating wastewater treatment and integrating digital infrastructure to monitor and manage processes in real time. This resulted in substantial improvements in data management, process automation, cybersecurity measures and operational integration, elevating the digital maturity from initial low levels to more advanced stages.

Despite these advancements, some areas like digital governance remain underdeveloped, indicating a need for future focus. The strong involvement of stakeholders and the existing digital competencies within Solvay provided a robust foundation for these improvements, ensuring that the project's innovations were effectively integrated into the company's operations. Moving forward, enhancing and formalising digital governance frameworks could be critical to fully realising the benefits of the digital transformation initiated by AquaSPICE.

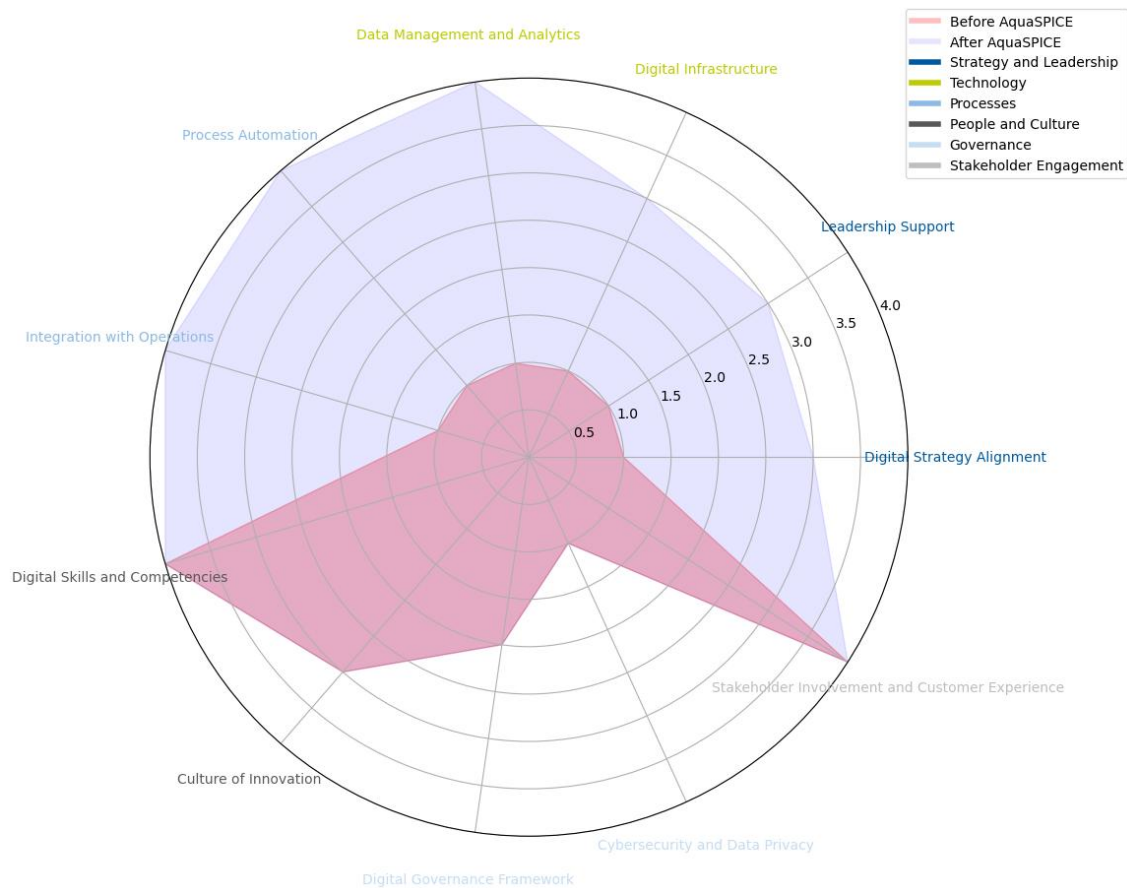


Figure 21- Digital Maturity Assessment for Case Study #2

The Figure 22 shows the analysis of the digital maturity in Case Study #3. It highlights significant advancements across several key areas, particularly in Digital Strategy Alignment, Data Management and Analytics, and Integration with Operations. The implementation of a real-time monitoring network, supported by 45 IoT sensors, has greatly enhanced the ability to continuously track water quality and quantity, allowing for more informed decision-making and operational efficiency. This shift from traditional data collection methods to automated, real-time analytics has improved the management of water resources, supporting critical activities like drinking water production and shipping. The project's innovative approach aligns with the stakeholders' long-term vision, fostering a culture of innovation and enhancing Digital Infrastructure and Governance Frameworks. While Process Automation and Leadership Support remain stable, the project has enabled valuable skill development in managing IoT systems, furthering the digital capabilities of stakeholders involved. Lastly, improvements in Stakeholder Involvement and Cybersecurity ensure that the system is both collaborative and secure, providing a solid foundation for future scalability.

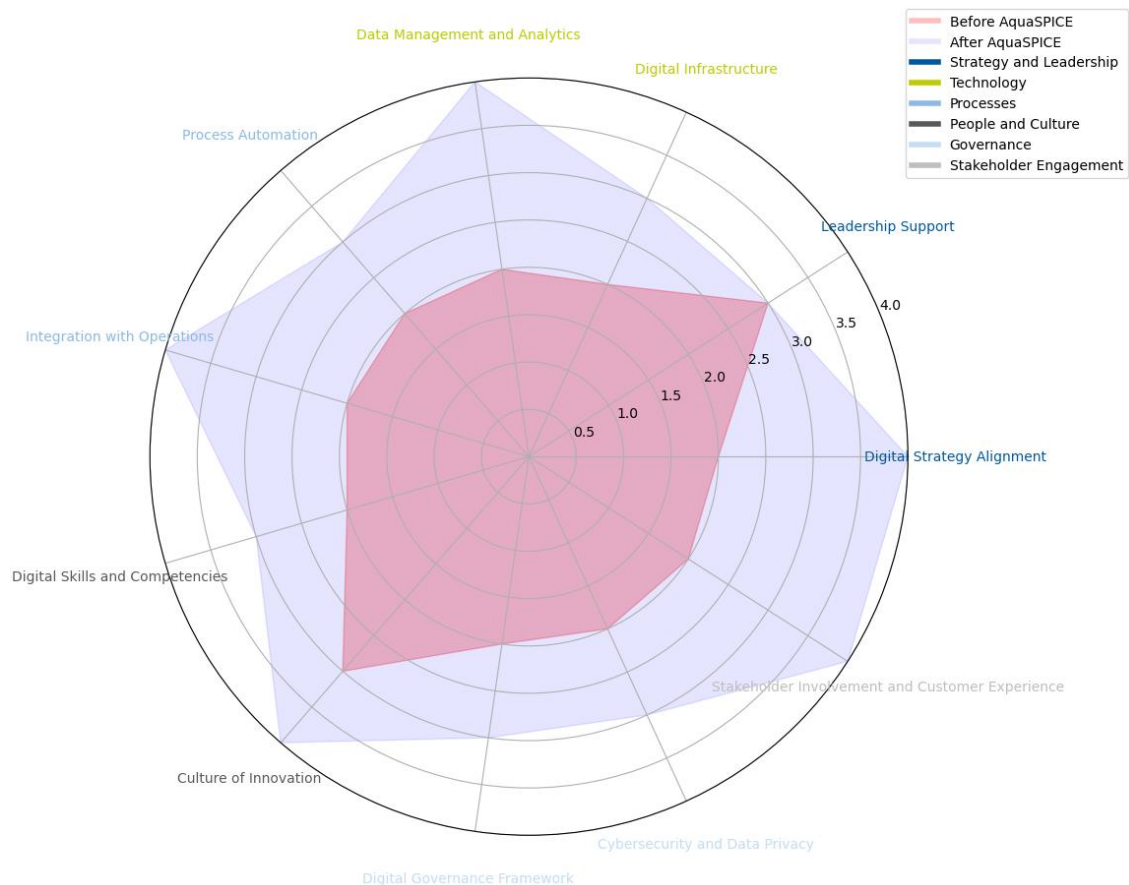


Figure 22– Digital Maturity Assessment for Case Study #3

Figure 23 shows incremental progress in certain aspects of the digital transition within the water management sector for CS#5, but also highlights areas where challenges persist. The most notable improvements are in the areas of Digital Strategy Alignment, Data Management and Analytics, and Stakeholder Involvement. Specifically, there is a growing understanding of the importance of digital strategy and analytics, which has led to better alignment and the development of new capabilities with IoT sensors and the RTM platform. Stakeholder Involvement has also seen a significant boost due to several consultations and training events that have engaged the community. However, the overall advancement remains limited in other areas, such as Leadership Support, Process Automation, and Digital Governance Framework. These areas either showed no improvement or very minimal progress. For instance, the lack of available resources and ongoing prioritization of other issues, have constrained the ability to advance leadership support and process automation. Digital Governance Framework and Cybersecurity and Data Privacy also remain underdeveloped due to coordination issues and a greater focus on manufacturing processes rather than water management. While there has been an enhanced understanding of digital innovation, the limited resources continue to be a bottleneck for significant progress across the board. This analysis suggests that while there is

positive movement towards digital transformation, more focused efforts and resource allocation are required to achieve substantial improvements in all areas.

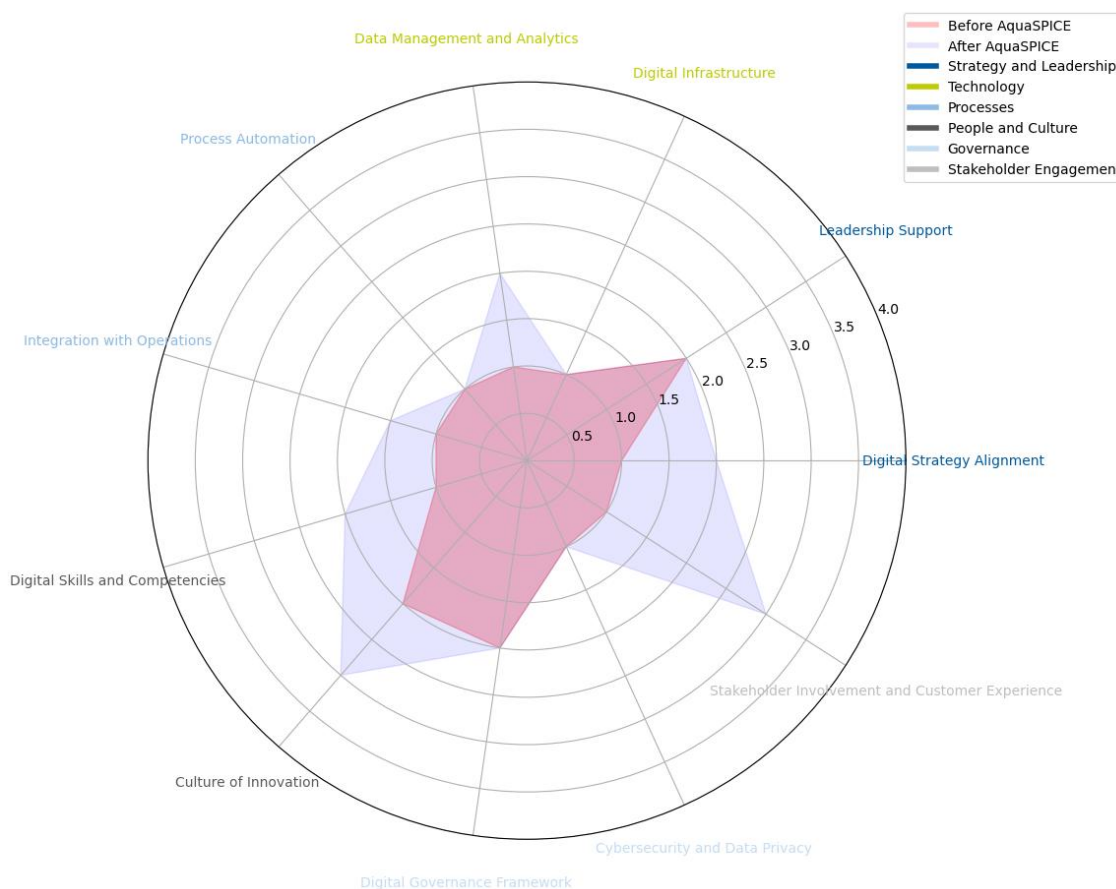


Figure 23- Digital Maturity Assessment for Case Study #5

Although at this stage, digitalisation of wastewater treatment plants at Tüpras is not yet considered a top priority as the main core business is the refinery facilities. However, with increasing concerns regarding the environment, digital innovation studies should be intensified to increase the performance of the wastewater treatment plants and unlock water reuse opportunities. For CS #6, as shown in Figure 24 below, while the AquaSPICE project has led to improvements in the know-how on digitalisation of water treatment units, some areas are still open for further improvement particularly in the implementation and integration of digital strategies. For example, while Digital Strategy Alignment has improved from a score of 1 to 3, indicating a more defined and partially integrated strategy, the lack of time required for full implementation still hampers the execution of such case studies and the ability to derive robust conclusions. Similarly, Leadership Support has also shown improvement, with inline objectives of organisation's future strategic plan. In areas such as Digital Infrastructure and Data Management and Analytics, progress is noted with the installation of sensors and online analysers, but the data collection and availability are time-consuming, requiring processes that need diverse workforce from different parties and hinder the operation capabilities of pilot plant processes, indicating that there is room for further enhancement. Despite these

advancements, areas such as Process Automation, Integration with Operations, and Digital Skills and Competencies remain stable with high scores, demonstrating a robust existing foundation. However, regulative requirements of stringent cybersecurity measures are present as in all similar industries, and require significant time to consolidate data sharing to external parties. Stakeholder involvement, also played a critical part for the improvement of the digital maturity, in which all other facilities of Tüpraş are onboard for the project improvements, which in turn resulted with the start of various internal projects related to wastewater treatment plant digitalisation. Overall, while there is progress, the improvements are uneven, and certain areas require more focused efforts to fully realise the benefits of digital transformation.

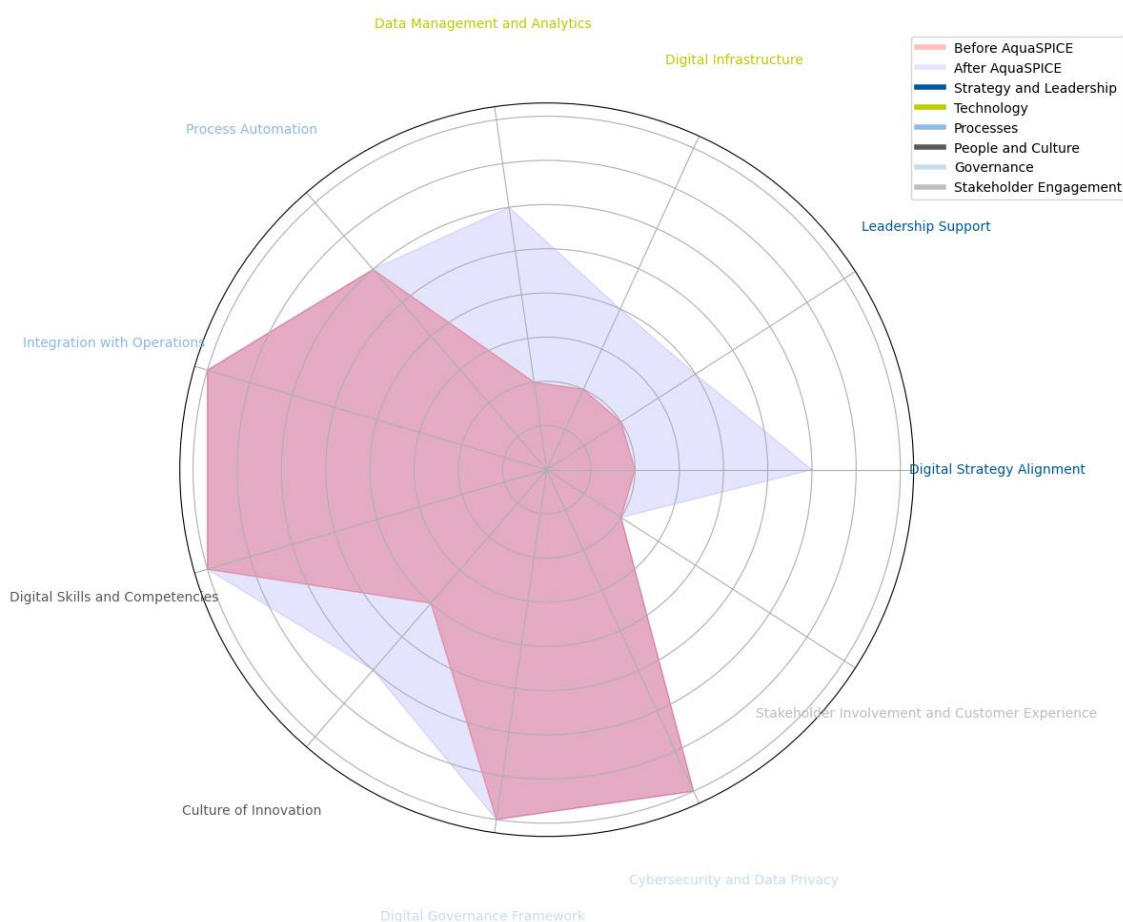


Figure 24- Digital Maturity Assessment for Case Study #6

6. Conclusion

The AquaSPICE industrial Water Efficiency Framework (WEF) is a pivotal outcome of the AquaSPICE project, designed to address the pressing challenges of industrial water efficiency. As the main output of Work Package 1, D1.6 (this report) represents a crucial step in the iterative process of refining, testing and validating the WEF through project Case Studies. These Case Studies serve as practical demonstrations of the framework's application, highlighting its relevance and effectiveness in guiding improvements in water efficiency within the process industry.

The report begins by setting the scope for the process industry and identifying the key challenges associated with industrial water efficiency, thereby establishing the necessity for a comprehensive framework. The validation of Phases 1-4 of the WEF, supported by ongoing Case Studies and other work package activities, has shown promising progress and is thoroughly documented in this deliverable.

The insights and developments presented in this report are not only reflective of the current state of the AquaSPICE WEF but also lay the groundwork for future enhancements. The WEF is envisioned as a dynamic and adaptive tool, evolving in response to the lessons learned during the project and the feedback received from the Case Studies and relevant work packages.

Looking ahead, the successful adoption and adaptation of the WEF by project partners will be instrumental in achieving long-term improvements in industrial water management. The framework is expected to serve as a living document, continuously refined and optimised based on real-world applications and emerging challenges in water efficiency. Ultimately, the AquaSPICE WEF aims to provide a robust and flexible guideline that can be adapted to various industrial contexts, ensuring sustainable water management practices across the industrial sector. This iterative approach not only strengthens the framework but also positions AquaSPICE as a leading initiative in advancing industrial water efficiency on a global scale.

7. References

- [1] “International Standard Industrial Classification of All Economic Activities,” New York, 2008.
- [2] Kimber. Simon, “Why industrial wastewater is as challenging as it is varied - industrial trade effluent - wastewater treatment industrial.” Accessed: Oct. 19, 2021. [Online]. Available: <https://www.wplinternational.com/news/industrial-wastewater-treatment-challenging-varied/>
- [3] “Wastewater and industry: the World Water Development Report | UNIDO.” Accessed: Apr. 06, 2021. [Online]. Available: <https://www.unido.org/news/wastewater-and-industry-world-water-development-report>
- [4] G. Young and C. Fernández-Jáuregu, “Water: a shared responsibility The United Nations World Water Development Report 2,” Feb. 2006.
- [5] S. Imenda, “Is There a Conceptual Difference between Theoretical and Conceptual Frameworks?,” *Journal of Social Sciences*, vol. 38, no. 2, pp. 185–195, Feb. 2014, doi: 10.1080/09718923.2014.11893249.
- [6] C. Robson and K. McCartan, “Real world research : a resource for users of social research methods in applied settings,” p. 533.
- [7] S. Donnaz, “Water reuse practices, solutions and trends at international,” vol. 6, Elsevier, 2020, pp. 65–102. doi: 10.1016/bs.apmp.2020.07.012.
- [8] S. B. Merriam and E. J. Tisdell, *Qualitative research : a guide to design and implementation*, 4th ed. John Wiley & Sons, 2015.
- [9] V. Anfara and N. Mertz, “Theoretical Frameworks in Qualitative Research,” SAGE Publications, Inc. Accessed: Oct. 27, 2021. [Online]. Available: <https://us.sagepub.com/en-us/nam/node/59225/print>
- [10] D. Briggs, “Making a difference. Indicators to improve children’s environmental health. Geneva: World Health Organisation.,” 2003.
- [11] de M. FF, de M. C. V, and F. A. CIR, “Development of Environmental Health Indicators for the Child Population: Report on a Brazilian Experience,” *Ann Glob Health*, vol. 83, no. 2, pp. 227–233, Mar. 2017, doi: 10.1016/J.AOGH.2017.02.003.
- [12] G. Dahlgren and M. Whitehead, “Policies and strategies to promote social equity in health”.
- [13] G. C. Gee and D. C. Payne-Sturges, “Environmental Health Disparities: A Framework Integrating Psychosocial and Environmental Concepts,” *Environ Health Perspect*, vol. 112, no. 17, p. 1645, Dec. 2004, doi: 10.1289/EHP.7074.
- [14] A. B. Knol, D. J. Briggs, and E. Lebet, “Assessment of complex environmental health problems: Framing the structures and structuring the frameworks,” *Science of The Total Environment*, vol. 408, no. 14, pp. 2785–2794, Jun. 2010, doi: 10.1016/J.SCITOTENV.2010.03.021.
- [15] P. Kristensen, “The DPSIR Framework,” 2004.

- [16] A. Romanelli, M. L. Lima, P. M. Ondarza, K. S. Esquius, and H. E. Massone, "A Decision Support Tool For Water Pollution and Eutrophication Prevention In Groundwater-dependent Shallow Lakes From Periurban Areas Based On The DPSIR Framework," *Environmental Management* 2021 68:3, vol. 68, no. 3, pp. 393–410, Jul. 2021, doi: 10.1007/S00267-021-01498-3.
- [17] S. R. Gari, C. E. Ortiz Guerrero, B. A-Urbe, J. D. Icely, and A. Newton, "A DPSIR-analysis of water uses and related water quality issues in the Colombian Alto and Medio Dagua Community Council," *Water Science*, vol. 32, no. 2, pp. 318–337, Oct. 2018, doi: 10.1016/J.WSJ.2018.06.001.
- [18] X. Song and B. Frostell, "The DPSIR Framework and a Pressure-Oriented Water Quality Monitoring Approach to Ecological River Restoration," *Water* 2012, Vol. 4, Pages 670-682, vol. 4, no. 3, pp. 670–682, Sep. 2012, doi: 10.3390/W4030670.
- [19] H. Sun, S. Ni, T. Zhao, and C. Huang, "The transfer and driving factors of industrial embodied wastewater in China's interprovincial trade," *J Clean Prod*, vol. 317, p. 128298, Oct. 2021, doi: 10.1016/J.JCLEPRO.2021.128298.
- [20] "The Embodied Energy of Tap Water | BuildingGreen." Accessed: Nov. 18, 2021. [Online]. Available: <https://www.buildinggreen.com/primer/embodied-energy-tap-water>
- [21] W. Mo, Q. Zhang, J. R. Mihelcic, and D. R. Hokanson, "Embodied energy comparison of surface water and groundwater supply options," *Water Res*, vol. 45, no. 17, pp. 5577–5586, Nov. 2011, doi: 10.1016/J.WATRES.2011.08.016.
- [22] M. Maktabifard, E. Zaborowska, and J. Makinia, "Energy neutrality versus carbon footprint minimization in municipal wastewater treatment plants," *Bioresour Technol*, vol. 300, p. 122647, Mar. 2020, doi: 10.1016/J.BIORTECH.2019.122647.
- [23] E. Szatyłowicz, I. Skoczko, P. Puzowski, A. Krawczyk, and A. R. Serrano, "Method of Estimating the Carbon Footprint of Wastewater Treatment Plants," *Environmental Sciences Proceedings* 2021, Vol. 9, Page 30, vol. 9, no. 1, p. 30, Nov. 2021, doi: 10.3390/ENVIRONSCIPROC2021009030.
- [24] P. Zawartka, D. Burchart-Korol, and A. Blaut, "Model of Carbon Footprint Assessment for the Life Cycle of the System of Wastewater Collection, Transport and Treatment," *Scientific Reports* 2020 10:1, vol. 10, no. 1, pp. 1–21, Apr. 2020, doi: 10.1038/s41598-020-62798-y.
- [25] S. Morera, L. Corominas, M. Poch, M. M. Aldaya, and J. Comas, "Water footprint assessment in wastewater treatment plants," *J Clean Prod*, vol. 112, pp. 4741–4748, Jan. 2016, doi: 10.1016/J.JCLEPRO.2015.05.102.
- [26] "Results – ULTIMATE Water." Accessed: Nov. 18, 2021. [Online]. Available: <https://ultimatewater.eu/results/>
- [27] "ULTIMATE WISIS Ontology." Accessed: Nov. 18, 2021. [Online]. Available: <https://aolite.github.io/WSISOntology/OnToology/wisis.ttl/documentation/doc/index-en.html>

- [28] B. Day and C. Lutteroth, "Climbing the ladder: capability maturity model integration level 3," *Enterp Inf Syst*, vol. 5, no. 1, pp. 125–144, Feb. 2011, doi: 10.1080/17517575.2010.495789.
- [29] Gartner research, "Use Gartner's Digital Business Maturity Model to Plan Your Digital Business Acceleration."
- [30] Deloitte, "Digital Maturity Model-Achieving digital maturity to drive growth," 2018.
- [31] EFQM, "The EFQM Model ."
- [32] S. D. Hariparsad, "Towards a Conceptual Framework for Understanding the Relationship between Policy and Practice," 2004, ch. 3.
- [33] S. McCombes, "What is a case study? | Definition, examples & methods," Scribbr.

8. Appendix: Detailed description of DMIs

Dimension	Criteria	Level	Description
Strategy and Leadership	Digital Strategy Alignment	1	There is no formal digital strategy in place. Digital initiatives are ad-hoc, isolated, and not aligned with overall business goals or water management objectives.
		2	A basic digital strategy is in place but is not fully integrated with overall business goals. Some digital initiatives align with water management objectives but lack a cohesive plan.
		3	The digital strategy is well-defined and partially integrated with overall business and water management goals. Most digital initiatives support key business objectives, but some gaps remain.
		4	The digital strategy is fully aligned with overall business and water management goals. All digital initiatives are strategically planned and contribute to achieving business objectives.
	Leadership Support	1	Leadership provides no support or commitment to digital initiatives. Digital projects are unlikely to receive necessary resources or attention.
		2	Leadership offers minimal support for digital initiatives. Some resources may be allocated, but commitment is inconsistent.
		3	Leadership demonstrates moderate support and commitment to digital initiatives. Adequate resources are provided, and digital projects are prioritised to some extent.
		4	Leadership is highly supportive and committed to digital initiatives. Significant resources are allocated, and digital transformation is a top priority.
Technology	Digital Infrastructure	1	Basic digital infrastructure is in place, but it is outdated and lacks advanced capabilities. Limited use of sensors, IoT devices, and connectivity.
		2	Developing digital infrastructure with some modern technologies. Moderate use of sensors and IoT devices, but connectivity and integration are limited.
		3	Advanced digital infrastructure with modern technologies. Extensive use of sensors, IoT devices, and robust connectivity.
		4	Optimised digital infrastructure with cutting-edge technologies. Full integration of sensors, IoT devices, and seamless connectivity.
	Data Management and Analytics	1	Data management is primarily manual, with limited automation. Data collection, storage, and analysis are inefficient and error-prone.

Processes	Process Automation	Basic automation is in place for data management. Data collection and storage are partially automated,	2	but analysis capabilities are limited.
		Integrated systems for data management and analytics. Automated data collection, storage, and	3	basic analytics capabilities.
		Advanced analytics capabilities with automated data collection, storage, and sophisticated analysis tools. Real-time data insights and predictive analytics are	4	used.
		Processes are predominantly manual, with minimal automation. Efficiency and accuracy are low. Some processes are semi-automated, improving efficiency but still requiring significant manual	1	intervention.
	Integration with Operations	Most processes are automated, significantly enhancing efficiency and accuracy. Minimal manual	2	intervention is required.
		Processes are fully automated, achieving maximum efficiency and accuracy. Manual intervention is rare.	3	
		Digital tools and systems are isolated and not integrated with operational processes. Data silos	4	exist, hindering efficiency.
		Digital tools are partially integrated with operational processes. Some data sharing occurs, but integration	1	is incomplete.
	Digital Skills and Competencies	Digital tools are fully integrated with operational processes. Data flows seamlessly across systems, enhancing efficiency.	2	
		Digital tools are seamlessly integrated with operational processes, enabling real-time data sharing and optimisation.	3	
		Workforce has basic digital skills and competencies.	4	
		Limited ability to support digital initiatives.	1	
People and Culture	Culture of Innovation	Workforce has developing digital skills. Some training and development programs are in place.	2	
		Workforce is skilled in digital technologies. Regular training and development programs are available.	3	
		Workforce has expert-level digital skills. Continuous learning and development programs are in place.	4	
		Organisational culture is resistant to change and innovation. Digital initiatives face significant	1	pushback.
		Organisational culture is neutral towards innovation. Some support for digital initiatives, but resistance	2	exists.
		Organisational culture is supportive of innovation.	3	
		Digital initiatives are encouraged and supported.	3	

Governance	Digital Governance Framework	4	Organisational culture is highly innovative. Digital initiatives are proactively pursued and celebrated.
		1	No formal governance framework for digital initiatives. Projects lack oversight and coordination.
		2	Basic governance framework in place. Some oversight and coordination of digital initiatives.
		3	Established governance framework with clear policies and procedures. Good oversight and coordination.
	Cybersecurity and Data Privacy	4	Advanced governance framework with comprehensive policies and procedures. Excellent oversight and coordination.
		1	Basic cybersecurity and data privacy measures in place. Vulnerabilities and risks are high.
		2	Developing cybersecurity and data privacy measures. Some improvements, but gaps remain.
		3	Advanced cybersecurity and data privacy measures. Good protection and risk management.
Customer and Stakeholder Engagement	Stakeholder Involvement	4	Optimised cybersecurity and data privacy measures. Excellent protection and risk management.
		1	No involvement of stakeholders in digital initiatives. Decisions are made in isolation.
		2	Stakeholders are informed about digital initiatives but have limited involvement.
		3	Stakeholders are consulted and provide input on digital initiatives.
		4	Stakeholders are actively involved in the planning and execution of digital initiatives.