D1.4 - The AquaSPICE Conceptual Water Efficiency Framework

WP1 - Water Efficiency Enhancement Applications Framework and Baseline Assessment

31/05/2023

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The AquaSPICE project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958396.

GRANT AGREEMENT NUMBER	958396	**ACRONYM**	AquaSPICE
FULL TITLE	Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations		
START DATE	01 December 2020	**DURATION**	48 months
PROJECT URL	www.aquaspice.eu		
DELIVERABLE	D1.4– The AquaSPICE Conceptual Water Efficiency Framework		
WORK PACKAGE	WP1 – Water Efficiency Enhancement Applications Framework and Baseline Assessment		
DATE OF DELIVERY	**CONTRACTUAL** 11/2021	**ACTUAL**	05/2023
NATURE	Report	**DISSEMINATION LEVEL**	Private/Public (later)
LEAD BENEFICIARY	KWR		
RESPONSIBLE AUTHOR	KWR		
CONTRIBUTIONS FROM	RWTH, TUC, EUT, ICCS		
ABSTRACT	Deliverable 1.4 is the output of Task 1.5 activities under Work Package 1 of the AquaSPICE project. This deliverable presents the conceptual Water Efficiency Framework (WEF) for the process industry. The framework is designed in a circular shape to reflect the continuous, iterative and adaptive process of enhancing water circularity, with the goal being to reach the desired outcome of advancing the sustainable water use of process industries. The framework also focuses on aspects related to the independent understanding of digital, process and circular innovations integrated with other aspects of industrial water efficiency. It also determines synergies, options, parameters and methods used to integrate the components that comprise each solution, to make them fully interoperable and define how they can be implemented in the factory and throughout the value chain, thereby avoiding conflicts. It is expected that the case studies and project partners adopt the insights and provisions of this report since the WEF is ought to be a continuous adaptive process and build upon the lessons drawn from the project period and the feedback from the case studies.		

Document History

VERSION	ISSUE DATE	STAGE	DESCRIPTION	CONTRIBUTOR
001	12/11/21		First draft	
002	17/11/21		Reviewed	Thomas Wintgens
003	18/11/21		For approval	
004	30/11/21		Submission	
005	01/05/23		Revised version considering CS#4 as voic case	Chuan Jiet Teo

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ABBREVIATIONS/ACRONYMS

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

1. Executive summary

Deliverable 1.4 is the output of Task 1.5 activities under Work Package 1 of the AquaSPICE project. This deliverable presents the conceptual Water Efficiency Framework (WEF) for the process industry. The conceptual framework is a step-by-step methodology that frames and outlines the architecture of the integrated technological solutions offered by the AquaSPICE project. This report has started setting the scope of the process industry and addressing the challenges of industrial water efficiency. Thus, the need for a framework to provide a guideline to improve the given situation. This deliverable also provides the definition and process of how this conceptual framework is developed. The background and unique opportunities of each case study are analysed to ensure that the framework has good coverage to account for the vast diversity of the differences in the process industry without compromising on the systemic approach in water management where efficiency can be achieved through an adaptation of appropriate technologies and practices on different levels.

The framework is designed in a circular shape to reflect the continuous, iterative and adaptive process of enhancing water circularity, with the goal being to reach the desired outcome of advancing the sustainable water use of process industries. The framework also focuses on aspects related to the independent understanding of digital, process and circular innovations integrated with other aspects of industrial water efficiency. It also determines synergies, options, parameters and methods used to integrate the components that comprise each solution, to make them fully interoperable and define how they can be implemented in the factory and throughout the value chain, thereby avoiding conflicts. This framework is structured from the exploration of the Drivers-Pressures-State-Impacts-Responses (DPSIR) framework due to its usefulness for the systematisation of information.

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.

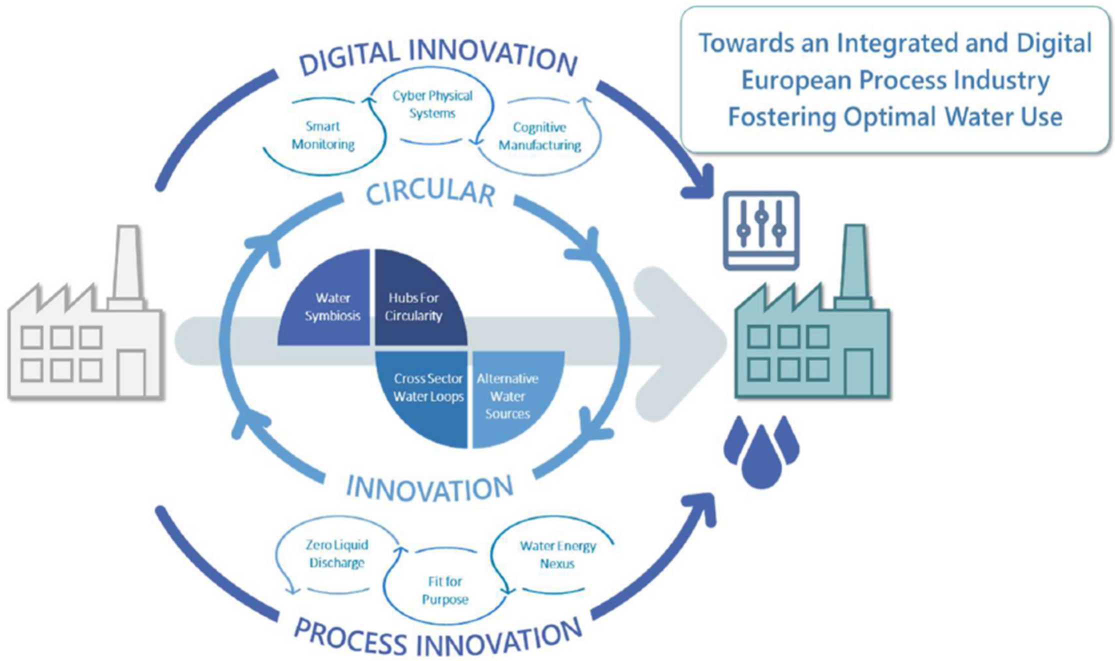

Figure 1 – AquaSPICE's 3 pillars towards a water efficient process industry.

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

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

2.2. Defining the Scope for the Process Industry

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

2.3. Challenges of Industrial Water Efficiency

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

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

2.4. Promoting Industrial Water Circularity

The concept of circular water management and 'closing the water loop' has gained attention in the industrial sectors to improve the environmental impact of industrial activities. One of the factors that lead to this approach is that water is becoming a scarce resource. Due to the current linear model of economic growth, degraded (waste)water is becoming unfit for further use by humans or the ecosystem. Furthermore, the total water withdrawal by industry is much greater than the water consumed, indicating the way water being consumed can be improved by a better efficiency scheme [4]. This can be achieved by adopting a holistic approach with innovations at water re-use solutions (State of the Art (SotA) practices and water re-use technologies) in different closed-loops levels (in-process and in-factory closed-loops as well as a symbiosis with other industries and sectors) as demonstrated in 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).

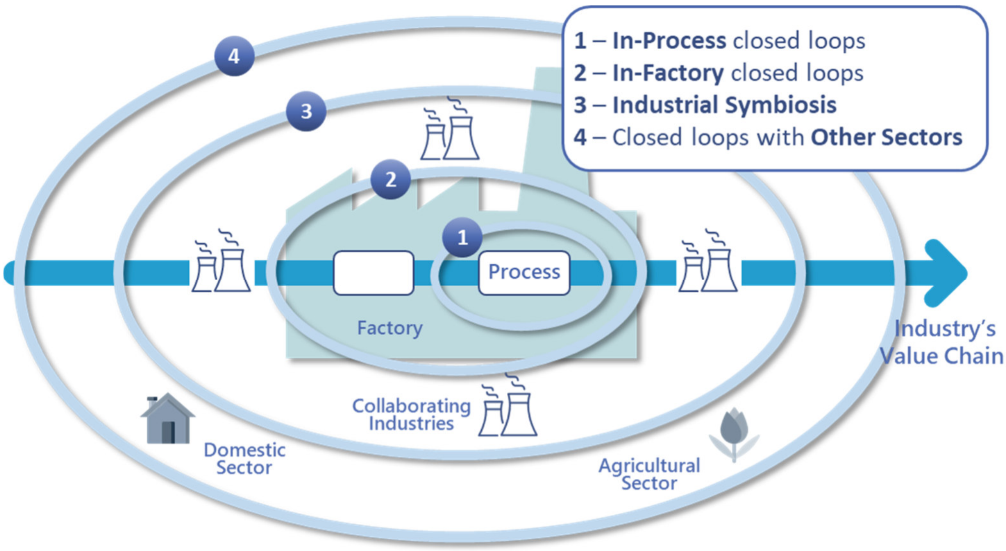

Figure 2 – Systemic approach in water management where water efficiency can be achieved in different levels: a single industrial process (unit operation), the entire factory, other collaborating industries (industrial symbiosis) or other sectors (e.g. domestic and/or agriculture)

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]–[9]. Through the aid of a conceptual framework, the user should be able to demonstrate the way key concepts (i.e. Digital, Process and Circular innovations for AquaSPICE) and their variables will converge to inform the phenomenon.

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

3.2. The need for a Water Efficiency Framework

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

3.3. Development of the Water Efficiency Framework

The goal of this conceptual framework is to provide a structural organisation to the segregated data and to frame these data into information that supply knowledge to the relevant parties and stakeholders; that in turn creates an understanding of supporting industrial water efficiency at the policy level and for practical applications at the industrial level as demonstrated in 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.

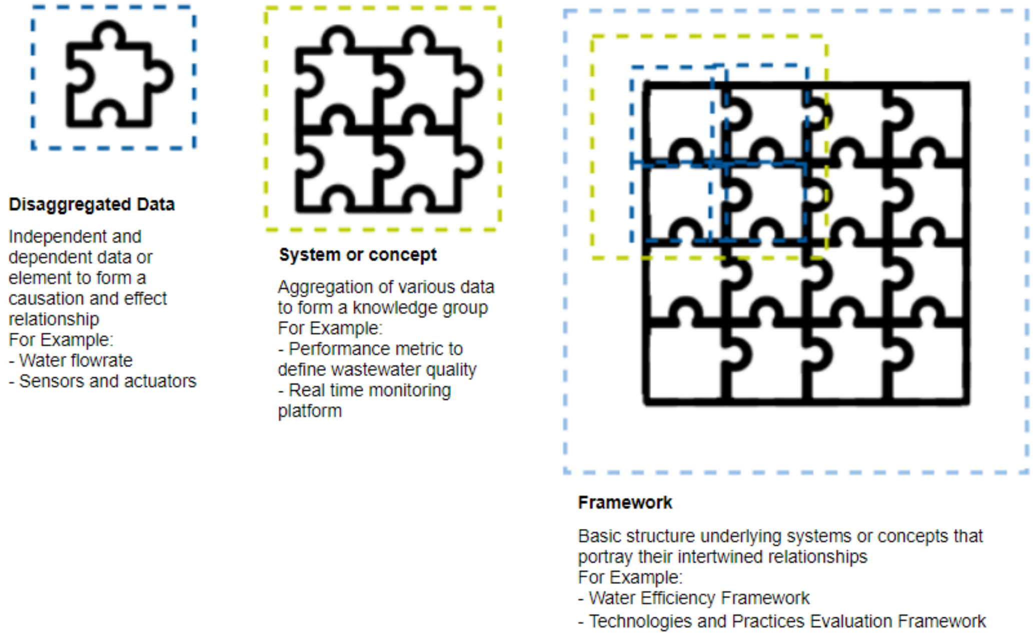

Figure 3 – Examples of some building blocks for the industrial WEF

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.

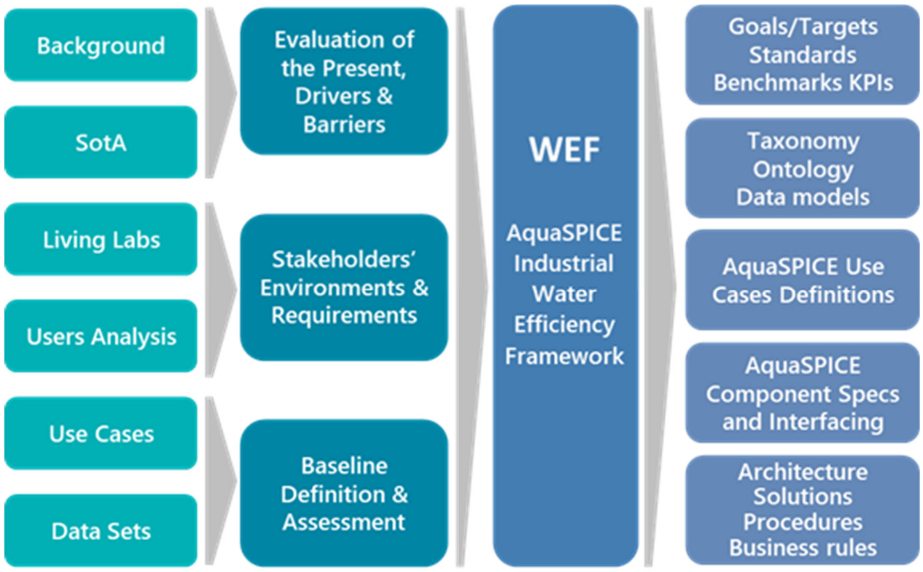

Figure 4 – Elements to be included in the WEF

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]–[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]–[18].

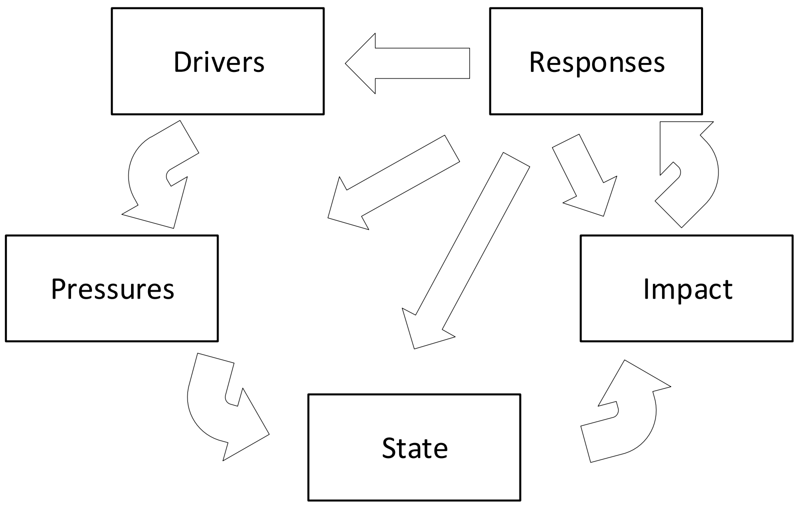

Figure 5–The skeleton of a DPSIR framework (adapted from [15]*)*

4. Front Runners of AquaSPICE Solutions

4.1. Background

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

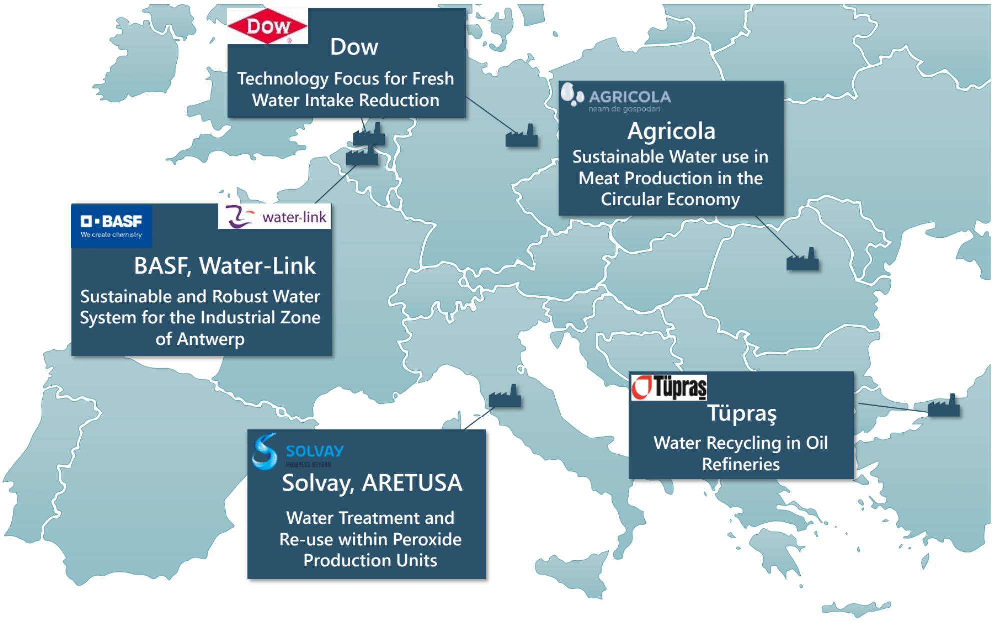

Figure 6– AquaSPICE Case Study locations

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

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

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

The unique opportunities identified for Case Study #1 are:

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

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

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

The unique opportunities identified for Case Study #2 are:

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

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

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

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

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

The unique opportunities identified for Case Study #3 are:

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

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

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

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

4.5. CS#4- Not Reported

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

4.6. CS#5- Sustainable Water Use in Meat Production

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 m^3/day. However, there are plans for expansion of the slaughterhouse, which will result in increased production and will likely significantly increase the daily average wastewater flow rate. Thus, there is a need to optimize the design and operation of the industrial wastewater treatment plant in order to become more water efficient and introduce the concepts of circular water management at AGRICOLA. The pilot case study to be implemented at AGRICOLA will deploy and explore smart solutions for sustainable water reuse and resource recovery, with the objective of improving water efficiency monitoring and achieving process optimisation.

The unique opportunities identified for Case Study #5 are:

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

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

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

The unique opportunities identified for Case Study #6 are:

- A blending of the streams will be optimised to decrease the amount of water discharged to the receiving water body;

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

5. User Analysis, Use Cases Requirements, and Quality Criteria

One of the most difficult aspects of a project is to understand, extract, and solidify in documented form the requirements of a project, Task 1.2 (User Analysis, Use Cases Requirements, and Quality Criteria) of the AquaSPICE project has developed a space for the co-creation environments for stakeholders' engagement as well as defining water requirements envelope, thus has also highlighted the importance of the involvement of stakeholder throughout the project. The 'users' or the stakeholders are "Individuals and organisations who are actively involved in the project, or whose interests may be positively or negatively affected as a result of project execution or successful project completion" [19], [20].

The shift towards circular water use in the process industry requires new and innovative, and sometimes highly technological solutions that connect different aspects of the value chain. These processes designed to solve water issues can also affect institutional structures, economic activities, social and cultural issues and the surrounding environment [21]. AquaSPICE recognises the importance of effective stakeholder engagement to improve the environmental and social sustainability of projects, enhance project acceptance, and collaborate to successfully implement the project design.

Every project is unique in its way but will always have many interested internal and external parties or customers, these users or stakeholders are from different subparts of the value chain of the project and need to be managed separately, based on their own set of standardised rules, routines, expectations and practices [22]. Thus, an inclusive and systematic approach throughout the project cycle and beyond is needed to support the development of strong, constructive, and responsive relationships that are important for the successful management of a project's environmental and social risks.

Stakeholder involvement is seen as particularly relevant for managing complex socio-technological problems due to scientific uncertainty and differences in values [23]–[25]. Thus, AquaSPICE's partners have realised the importance of stakeholder participation in the early phases of developing solutions to ensure that all perspectives by actors involved are taken into account and have captured these stakeholders engagement activities in Deliverable 1.2: Stakeholder Engagement and Design of co-creation environments. To date, the AquaSPICE project partners have successfully engaged 56 stakeholders across all use cases. Accordingly, surveys, workshops and analysis have been carried out not only to understand the user requirements (e.g. related to water quantity and quality criteria, which will be reflected in Task 1.3 as tailored Key Performance indicators (KPIs) for each case study) but to also reflect there is an imminent need for technological innovations to enable water closed loops and efficient water (re)use across industries. The lack of awareness across sectors on the importance of water as a product poses a challenge hence highlighting the need to enhance the dissemination of the project goal and purpose, thus raising social awareness on the need to consume water more efficiently and circularly.

Furthermore, the findings and outcomes derived from Task 1.2 include the fact that stakeholders have specific concerns that can act as barriers preventing them to engage in activities such as local laws or regulations, lack of awareness and/or engagement with the cause (i.e. water re-usage) as well as lack of funding, innovation programmes and implementation methodologies that would allow them to adopt new solutions. It should also be considered that institutional stakeholders have a limited time to devote to such activities and it may also be the case that they have had bad prior experiences in engaging with innovative technologies (i.e. engagement results that remained unused, rushed implementation of new technologies that proved very costly).

Nonetheless, the findings from Task 1.2 have shown that there is an increased willingness by stakeholders to participate and support the cause of AquaSPICE by engaging with technology partners to design efficient solutions to address their needs.

Another key finding from the analysis of Task 1.2 that should be considered is that interaction with the stakeholder community has shown that culture is an important factor to keep in mind; cultural differences mean that different methods need to be adapted to engage with people. These analyses have provided an opportunity and a basis for the AquaSPICE project partners to organise strategic planning activities (case study focused Communities of Practice (CoP)s and Living Labs that will be defined and designed in this task but implemented at each case study location- Work Package (WP) 6) to identify and support the interests of the key groups and to layout, a business case orientated concept for future stakeholder engagement activities tailored to their respective needs (as part of the business strategy developed in WP7) and levels of influence and aligning the project accordingly [20].

6. Use Cases Definition with Baseline Assessment

The purpose of the baseline assessment carried out in Task 1.3 is to describe the baseline conditions of each of the use cases (see Section 4) before the implementation of the case studies. This includes assessing all relevant pre-existing infrastructures and systems and provide benchmark information for constructing a model of assessment to measure project achievements and outcomes quantitatively based on the project's vision and scope, to determine progress and adjust project implementation to best satisfy the requirements of stakeholders (see Section 5). The other main goal of the baseline study is to uphold accountability and inform the impact evaluation to compare and measure the difference the project is making, more precisely to set the benchmark values of individual case studies and to create a bridge to WP2 as a starting point for appropriate innovative technology design and the synthesis of each use case's boundaries. Descriptive models & attributes, internal & external environments, constraints, actors, goals and targets will be fed into WP6 (assessment of performance in case study demonstrations). Furthermore, a special focus is put on the technological units (digital and process) which were already in place before AquaSPICE and the available flow streams as resources for the new AquaSPICE circular innovations. These as-is situation values will be used to identify the extent to which change has happened throughout the project lifecycle and the improvement at each level of the project to ease the fine-tuning of future adjustment. Relevant data of these water streams (quantity and quality) were collected in the frame of this deliverable to describe the baseline conditions, as well as demonstrate the feasibility of innovative technological solutions supporting a circular water transition in the process industry.

7. The Conceptual Framework

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

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

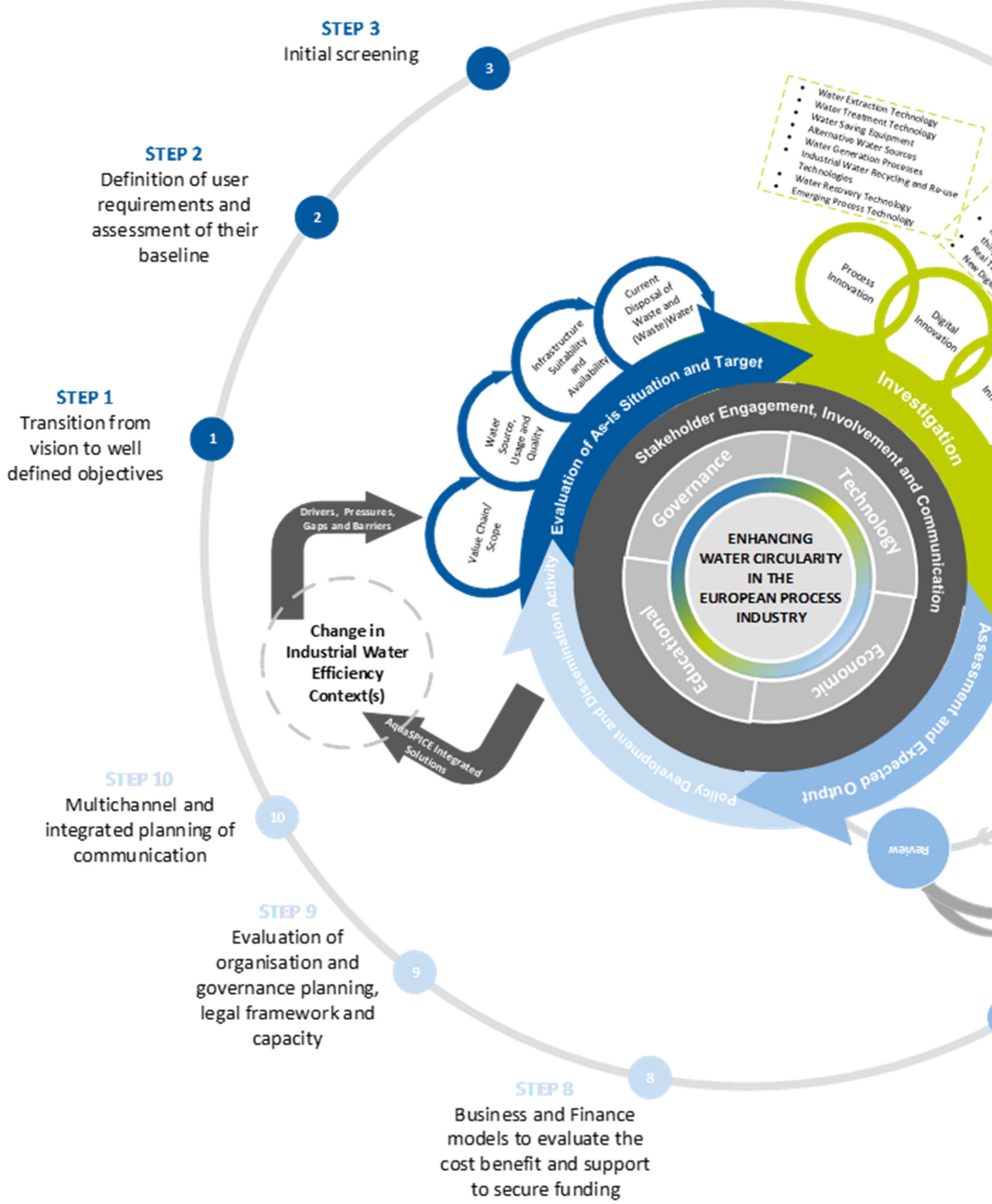

Figure 7:

1. Evaluation of As-is Situation and Target

2. Investigation
3. Assessment and Expected Output
4. Policy Development and Dissemination Activity

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

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

These changes are sometimes unpredictable and hence the steps in the Conceptual Framework are designed in a way where the process is devised in an adaptable loop and regular feedback and improvement can be carried out throughout the project cycle and even revisited when new contexts (drivers or challenges) occurred within the scope of the framework. An important aspect in the development of this framework is its ability to provide unique solutions to respond and accommodate multiple outcomes. However, like in any framework, periodic checks and revisions of the components in the framework would be necessary to ensure it is progressive and still remains fit for purpose.

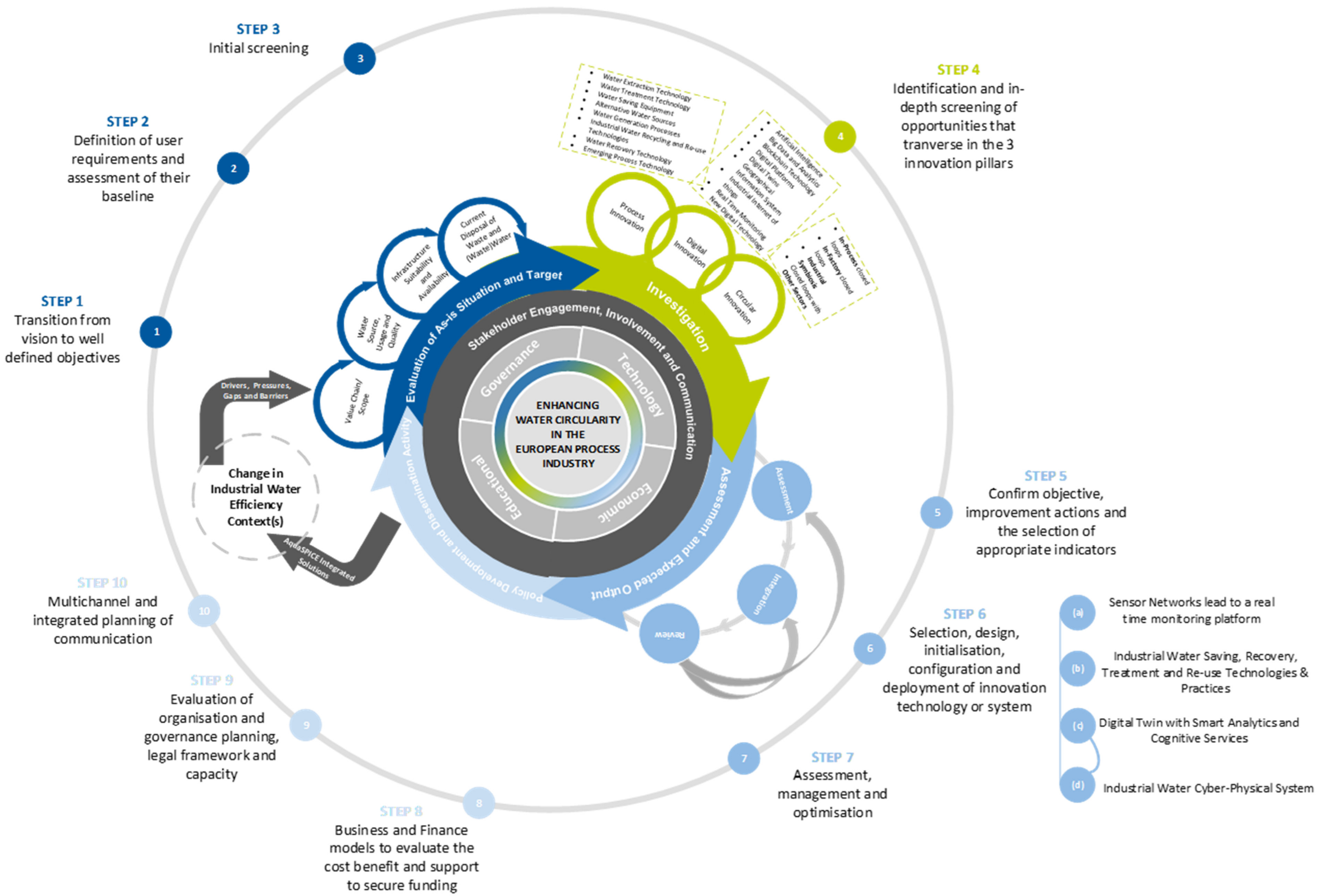

Figure 7– Conceptual Water Efficiency Framework for AquaSPICE

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

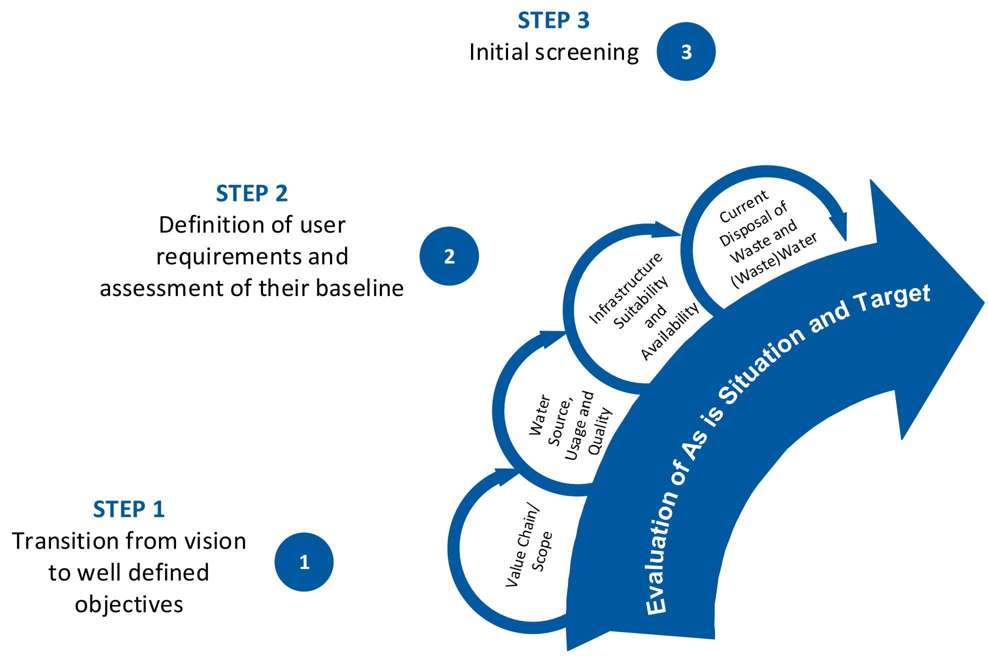

Figure 8– Evaluation of as-is situation and target

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

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

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

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

7.1.3. 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 loops 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.

7.2. Phase 2: Investigation

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

The second phase of the framework is the investigation 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 1. 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.

7.3. Phase 3: Assessment and Expected Output

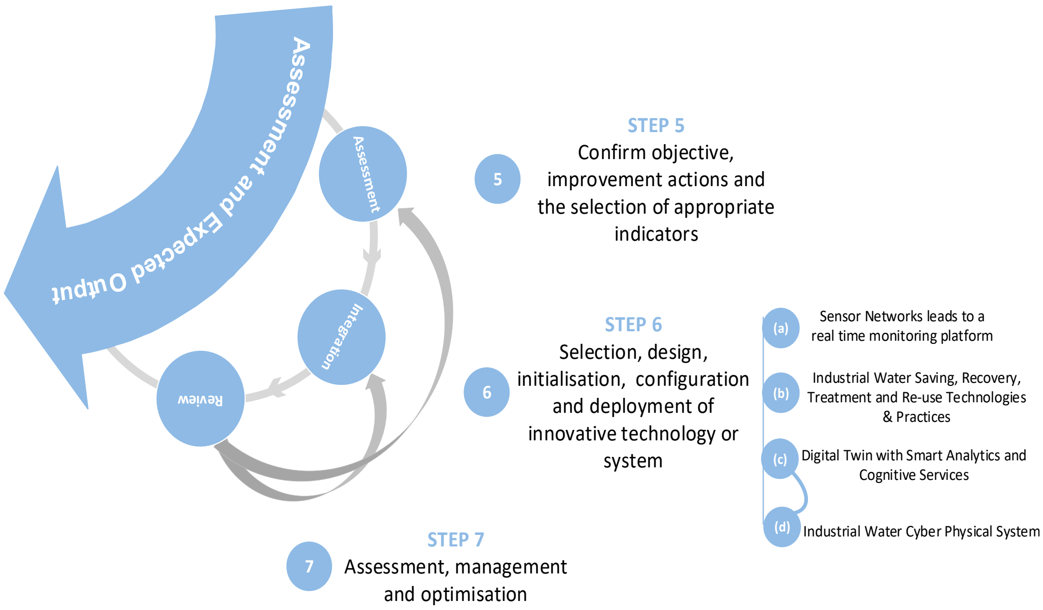

Figure 10– Assessment of AquaSPICE solutions and expected output

7.3.1. 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 [26]–[32] . An extensive list of more specific indicators can also be generated to ensure the coverage of the broad European process industry category.

7.3.2. 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 11 shows an example of the ontology for the ULTIMATE project - an H2020 project on water smart industrial symbiosis.

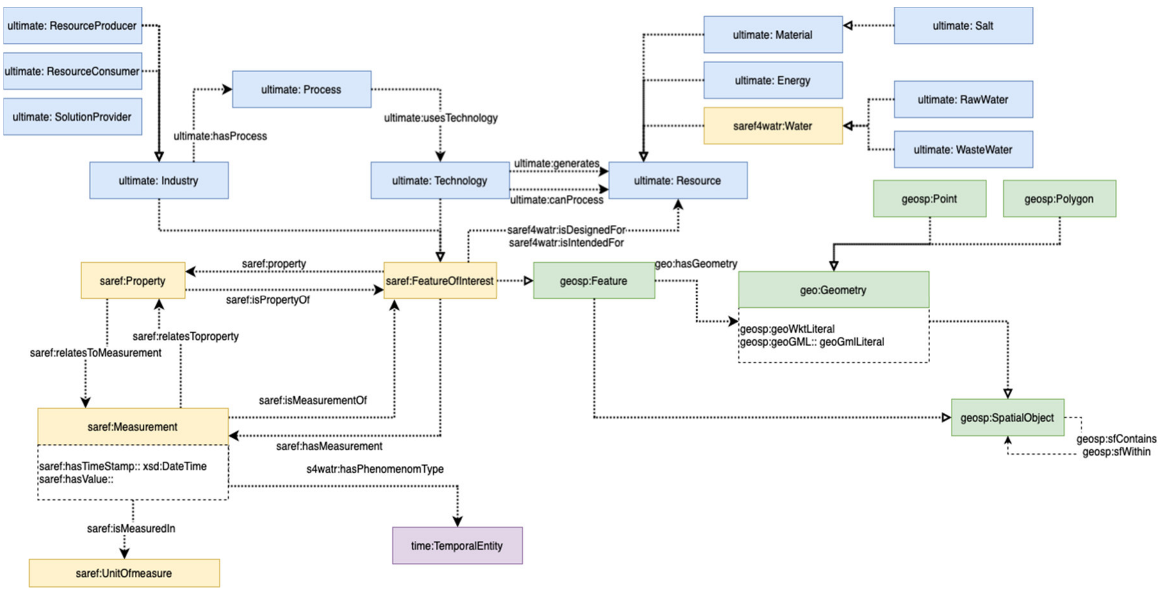

Figure 11– An example of ontology developed for the ULTIMATE H2020 project as the knowledge graph to be shared by individuals who participate in the given domain [33], [34]

Holistic modelling concepts, such as dynamic Life Cycle and Life-Cycle-Cost Assessment will be incorporated to string the work of work packages together. Through the work of these modelling concepts, the optimal and integrated water reuse schemes (including water symbiosis) can be quantified and visualised.

7.3.3. Step 7: Assessment, management and optimisation

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

7.4. Phase 4: Policy Development and Dissemination Activity

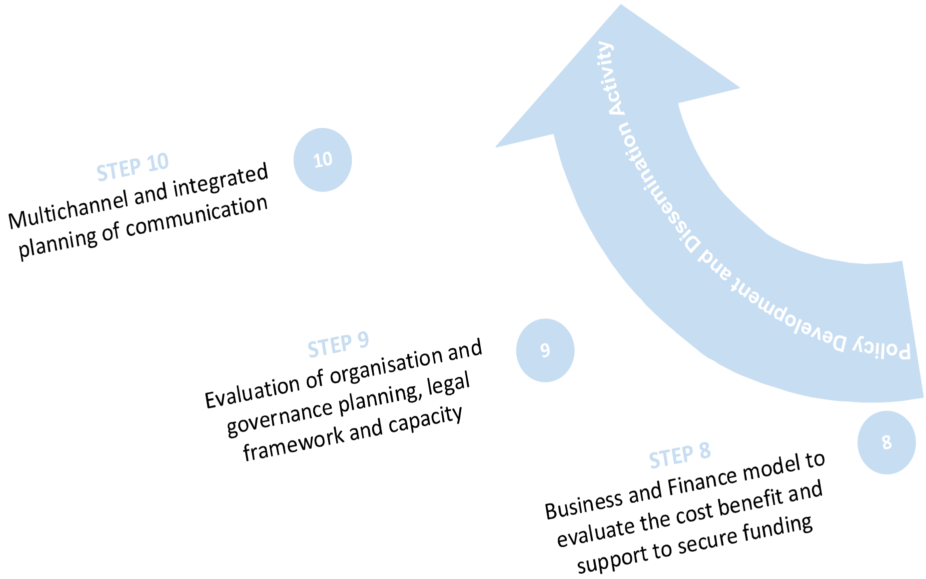

Figure 12– Policy development and dissemination activity

7.4.1. 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.

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

As discussed in Section 5, 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.

7.4.3. 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.

8. Conclusion and Future Work

The AquaSPICE industrial WEF is a key output of the AquaSPICE project. This report has provided a conceptual design for water efficiency enhancement which will be used by the case studies to further define and refine the components of AquaSPICE solutions, their specifications and their interfacing and interoperability. As only the baseline scenario is available at this period of the project, the descriptive model is yet to be formulated. Since the project is ongoing and the coming months will provide more modelling outputs and formulation of policy scenarios, the conceptual WEF developed so far and described in this report is preliminary and provides an initial milestone sufficiently robust to provide further directions towards its full realisation. The material presented here is an important part of the development of the AquaSPICE Application WEF and to collate the component of the project solutions, and refine the framework in the months ahead. In addition, this interim report wishes to serve as a summary of the current position in the AquaSPICE application WEF work and development and what can be built further upon. The phases and steps of the framework are as follows:

Phase 1: Evaluation of As-is Situation and Target

- Step 1: Transition from vision to well-defined objectives
- Step 2: Definition of user requirements and assessment of their baseline
- Step 3: Initial Screening

Phase 2: Investigation

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

Phase 3: Assessment and Expected Output

- Step 5: Confirm objectives, improvement actions and the selection of appropriate indicators
- Step 6: Selection, design, initialisation, configuration and deployment of innovative technology or system
- Step 7: Assessment, management and optimisation

Phase 4: Policy Development and Dissemination Activity

- Step 8: Business and Finance model to evaluate the cost-benefit and support to secure funding
- Step 9: Evaluation of organisation and governance planning, legal framework and capacity
- Step 10: Multichannel and integrated planning of communication

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

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