D1.1- APPROACHES TO INDUSTRIAL WATER EFFICIENCY

WP1 - WATER EFFICIENCY ENHANCEMENT APPLICATIONS FRAMEWORK AND BASELINE ASSESSMENT

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ABSTRACT	Deliverable 1.1 is the output of Task 1.1 activities under Work Package 1 of the AquaSPICE project. This report provides an overview of circular water use in the European industrial process sector, indicating the current trend of industrial water use and also, the future focus and potential directions. This report aims to identify gaps, barriers and existing approaches to industrial water efficiency by considering the existing State of the Art literature review for current industrial water efficiency practices, technologies and water monitoring approach, followed by a review of relevant policy directives and regulations implying the latest advances on SPIRE and H2020 projects. In this report, several gaps influencing industrial water efficiency are identified and can be categorised into technical, legislation, social and economic areas of considerations to be addressed, a summary of how AquaSPICE's work can address these gaps was also presented in the report. A review has been done on the relevant past and on-going EU projects with a focus on the SPIRE projects to understand synergies of these projects with AquaSPICE and the transferrable knowledge and related concept to AquaSPICE has been tabulated. Finally, a review of state of the art in current industrial practices was conducted, where some good industrial practices incorporating process, circular and digital innovations to enhance industrial water efficiency are discussed.			

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ABBREVIATIONS/ACRONYMS

AquaSPICE	Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations
ACF	Activated Carbon Filters
AEM	Anion Exchange Membrane
AI	Artificial Intelligence
AOPs	Advance Oxidation Processes
BAC	Biological Activated Carbon
BOD	Biological Oxygen Demand
CAPEX	Capital Expenditure
CAS	Conventional Activated Sludge
COD	Chemical Oxygen Demand
CPS	Cyber Physical Systems
DAF	Dissolved Air Flotation
ED	Electrodialysis
EDR	Electrodialysis Reversal
EU	European Union
GAC	Granular Activated Carbon
H2020	Horizon 2020
IE	Ion Exchange
IIoT	Industrial Internet of Things
IoT	Internet of Things
ISO	The International Organisation for Standardisation
MBR	Membrane Bioreactor
MED	Multi-Effect Distillation
MF	Microfiltration
MSF	Multi-Stage Flash
NF	Nanofiltration
OPEX	Operational Expenditure

PEM	Proton Exchange Membrane
RO	Reverse Osmosis
SotA	State of the Art
SPIRE	The Sustainable Process Industry through Resource and energy Efficiency
TSS	Total Suspended Solids
UF	Ultrafiltration
ZLD	Zero Liquid Discharge

1. Executive summary

Deliverable 1.1 is the output of Task 1.1 activities under Work Package 1 of the AquaSPICE project. This report provides an overview of circular water use in the European industrial process sector, indicating the current trend of industrial water use and also, the future focus and potential directions. This report aims to identify gaps, barriers and existing approaches to industrial water efficiency by considering the existing State of the Art literature review for current industrial water efficiency practices, technologies and water monitoring approach, followed by a review of relevant policy directives and regulations implying the latest advances on SPIRE and H2020 projects.

Globally, approximately 20% of all freshwater consumption is used for industrial purposes. With the rapid development in industrialisation, water consumption is expected to increase, and as a result, producing a higher volume of wastewater in the process. There are enormous potential and opportunities for the process industries to look into a more circular and resource efficient approach towards the current practices of freshwater abstraction and wastewater discharge. The circular approach can be enabled for various drivers, including:

1. Factors that influence the future supply of water such as water stress, climate change, availability of freshwater resources and stringent policies towards water abstractions and emission.
2. Factors of continuous process improvement such as Zero Liquid Discharge, industrial symbiosis, the shift towards industry 4.0 and ultimately reducing cost and improving water and environmental footprint.

In this report, several gaps influencing industrial water efficiency are identified and can be categorised into technical, legislation, social and economic areas of considerations to be addressed, a summary of how AquaSPICE's work can address these gaps was also presented in the report. A review has been done on the relevant past and on-going EU projects with a focus on the SPIRE projects to understand synergies of these projects with AquaSPICE and the transferrable knowledge and related concept to AquaSPICE has been tabulated.

Finally, a review of state of the art in current industrial practices was conducted, where some good industrial practices incorporating process, circular and digital innovations to enhance industrial water efficiency are being named and famed. To ensure the treated water quality is fit for the purpose for reuse, the selection of water technologies is crucial, hence a study of current water treatment technologies was also carried out and summarised into mechanical processes, thermal processes, biological processes and chemical processes. In terms of digitalisation, the latest advances in artificial intelligence, interoperability and deep learning denote the huge interests of the industry in the process of symbiosis and resource reuse to make the industries more competitive and sustainable. At the governance level, there are movements towards the expansion of water and industrial data spaces, as places to share data and digital assets in order to increase the knowledge about the water and industry with the vision of tackle holistic policy-making that benefits both sectors.

In conclusion, the traditional linear business model in the industrial sector is no longer sustainable nor friendly to the finite water resources. Accordingly, a more sustainable approach will be employed in AquaSPICE, where a holistic methodological and technical water efficiency enhancement framework that encompasses all aspects of industrial water management will be developed and deployed. This includes the 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). The framework will be beneficial to be used as guides and pointers concerning materialising circular water use in the European process industries.

2. Introduction

2.1. The AquaSPICE Project

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

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.

These approaches will be developed and adapted in 6 Case Studies, involving 8 industrial actors (Dow, BASF, Water-Link, Solvay, ARETUSA, Agricola, JEMS and TUPRAS) in 6 EU countries (Germany, Netherlands, Belgium, Italy, Slovenia and Romania) and 1 associated country (Turkey).

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 organizational 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 Task 1.1 being a review of the “Approaches to Industrial Water Efficiency, Drivers and Barriers”.

2.2. Approaches to Industrial Water Efficiency, Drivers and Barriers

Task 1.1 (Deliverable 1.1) aims to identify gaps, barriers and existing approaches to industrial water efficiency. It is part of AquaSPICE wider study and aims to materialise circular water use in European Process Industries by considering the existing State of the Art (SotA) literature review for existing industrial water efficiency practices, technologies and water monitoring approaches, followed by a review of relevant policy directives and regulations and finally, having an outlook of relevant SPIRE and H2020 projects.

3. Drivers and Barriers for Industrial Water Efficiency

3.1. Current Industrial Water Efficiency Trend

The process industry is one of the main pillars of the European economy and is water intensive. Water is used for a range of different process industrial applications ranging from using it as raw material, in manufacturing processes and operations, as dilution, for washing and cooling of the process units [1]. Globally, approximately 20% of all freshwater consumption is used for industrial purposes and this amount varies greatly between countries. For instance, in Europe and North America, about 50% of the total freshwater abstraction is accounted for industrial water use and between 4-12% in developing nations. This number is predicted to grow by a factor of 5 in industrialisation developing countries. Industrial wastewater effluents typically originated from sanitary wastewater, cooling tower, process wastewater and cleaning wastewater from cleaning and maintenance of industrial areas. However, the extent of industrial wastewater generation remains largely unknown due to a deficiency in the available data and information [2]. Despite the huge potential to tackle water scarcity, industrial (waste)water management is often underlooked and has become a barrier to overcome to complete the transition towards a more circular economy.

Different countries withdraw water in different shares for different sectors. High income countries tend to have a higher ratio of freshwater abstraction for industrial use (16.84%) compared to low income countries (1.70%) [3]. Further, the water abstraction for anthropological activities generates wastewater streams. High income countries treat a significantly higher amount of wastewater compared to upper middle income countries, lower middle income countries and low income countries, with a ratio of 70%, 38%, 28% and 8% respectively [4].

In Europe, more than 40,000 million m^3 of wastewater is treated every year but only about 964 million m^3 of this treated wastewater is reused [5]. The degree of wastewater reuse in Europe differs significantly across different countries [6]. While the drive of this difference could be due to the availability of local freshwater supply, nevertheless, the potential of reclaiming wastewater remains an underexploited resource [4]. Industrial water reuse can be defined as water that is used more than once in an industrial setting. However, this water typically has to be treated for a fit for purpose end use to ensure a high efficiency reuse [7].

The future potential for reusing treated effluent is enormous. Without a doubt, the process industries have a major role to play in transforming their policies and operations to enhance water efficiency in an innovative manner and this can be approached through AquaSPICE's three pillars (Process innovation, Circular innovation and Digital innovation, see Figure 1). The process industries are responsible for pivoting their role in addressing the water stress regional context, as well as their value chains. In this section of the report, several drivers and gaps influencing industrial water efficiency are identified.

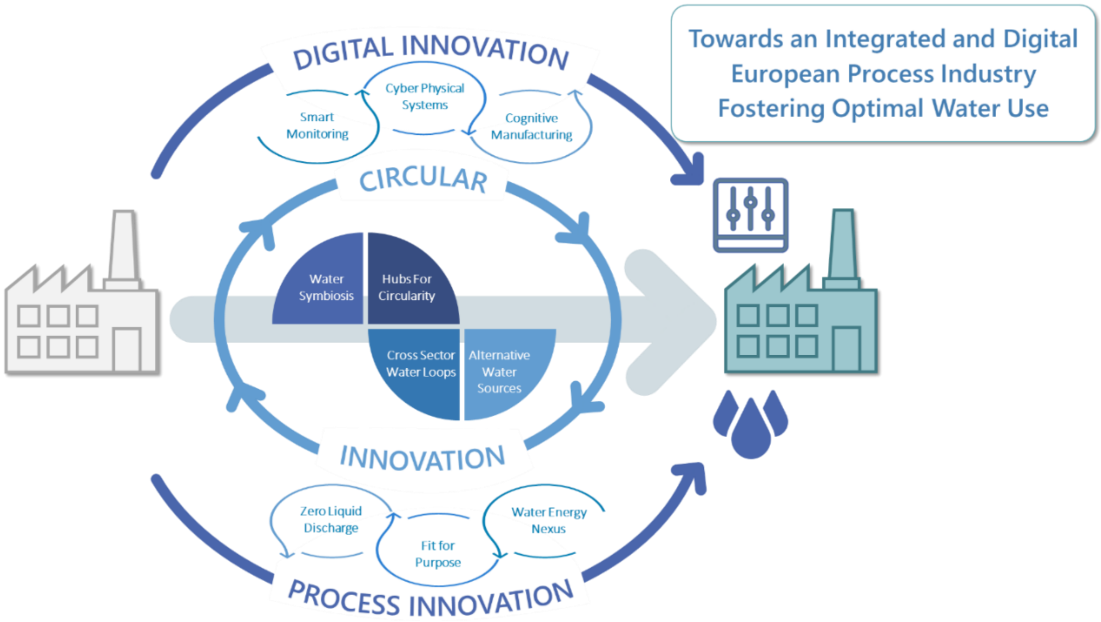

Figure 1- AquaSPICE's 3 pillars approach to address industrial water efficiency

3.2. Drivers and Opportunities for a Better Water Efficiency in the Process Industry

3.2.1. Water Stress and Climate Change

Freshwater is a precious resource, for instance, one-third of European countries have relatively low availability of water, hence the exploration of industrial wastewater reuse has been considered as a promising approach to address water stress [8]–[11]. Water stress exists in many countries, particularly in areas with low rainfall, development in human activities such as intensive water demanding industries which are also, among many, one of the root causes of the problem. Thus, the use of reclaimed industrial wastewater as an alternative water resource has been considered [12], [13]. About one-third of European countries have relatively low availability of water, coupled with the projections of the adverse effect on freshwater resources (loss of wetlands, desertification, low river flow, and the intrusion of saltwater) due to climate change, causing the water supplies less reliable [3], [9], [14]–[16]. Furthermore, industrial development escalated the water demand in some of the industries, in Europe, about 53% of abstracted water is for industry [9], [17]. With the increasing demand for these activities, the water management practices have moved towards the more efficient use of water by reducing abstraction, less wasteful use of water, more efficient appliances and water reclamation. Previous studies have shown that the reclamation of treated wastewater of specific water quality criteria can be considered for different reuse purposes, hence, it was proposed that the industrial effluent can be treated onsite to meet the requirements for process water applications [12].

3.2.2. Competition for Fresh Water Resources

On a global economic scale, water is on par or a more important resource than either oil or gas as access to sufficient freshwater is vital to many businesses [18], [19]. Besides population growth and increasing urbanisation, intensive business activities such as agriculture, tourism and industrial activities play a major part in competing for the available freshwater resources [6]. Being a mounting pressure, the distribution of freshwater resources has to be competed for and linked to various national and international social, environmental and economic policies [20], [21]. Water as a limited resource and required for diverse applications cannot be easily evaluated in monetary terms nor defined in a free market economy, and the competition and tension that lie within cannot be broadly categorised into a physical competition or an economic competition. This, therefore, creates additional tension and competition for water resources users, both at a regional and international level [22]. It is very likely that the tension of water-related disputes will increase in the future, and nevertheless, this competition encourages a more eco-efficient and sustainable industrial water management, leading to a circular approach in industrial water use, considering industries are among the biggest freshwater users.

3.2.3. Toxic Emissions and Stringent Policies

Industrial emissions to water are very complex, with different underlying environmental issues at stake, and the conventional wastewater treatment infrastructure is generally not designed to treat industrial water pollutants. EU has the Industrial Emission Directive and other water policies that aim to protect the water ecosystems from industrial emissions while supporting economic growth and competitiveness. This EU legislation imposes a case-by-case permit for large industrial operators, which contains emission limit values to water. Moreover, the EU carries out a periodical fitness check on these policies to assess whether the Water Directives (including the Inductrial Emission Directive) are still fit for purpose by examining their performance against the criteria set out in the Commission’s Better Regulation agenda: effectiveness, efficiency, coherence, relevance and EU added value [23]. The positive influence of these stringent policies is reflected in the decrease of the emission of industrial pollutants into the water as shown in Figure 2 [24].

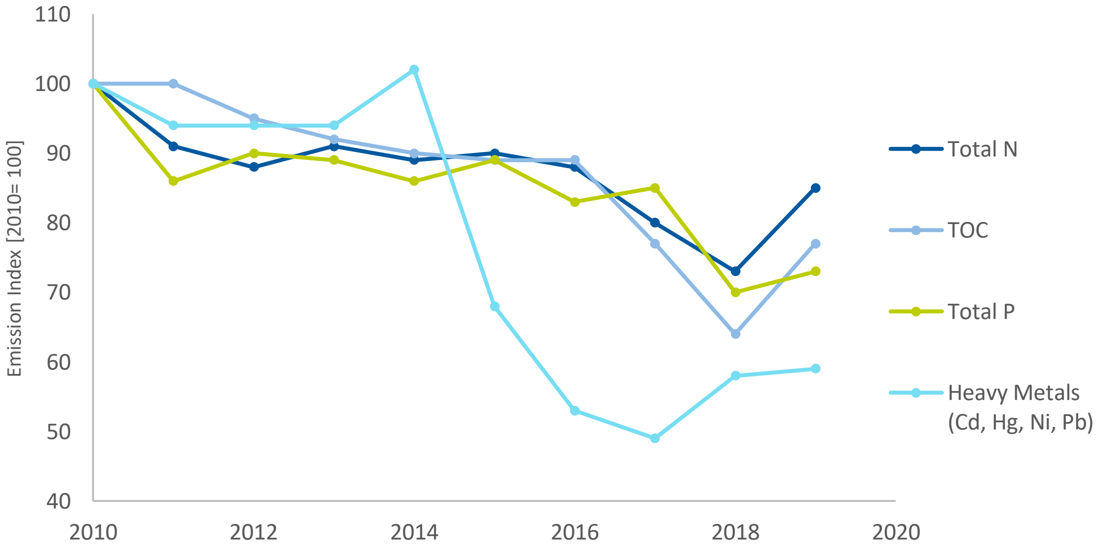

Figure 2- Industrial releases of pollutants to water in the EU-27 Member States from 2010 to 2019

At the global level, as the epicentres of the world economy, India and China are experiencing rapid industrialisation and thus, have an enormous prospect and opportunity to shift their current wastewater schemes to sustainable growth models that have long-term financial and environmental benefits.

In the case of India, this rapid industrial development causes toxic emissions and effluent from industries thus creating an increasing environmental problem [25], which has resulted in a stricter approach towards the standards of compliance under the Environmental Protection Act 1986. The industries are only allowed to discharge the effluent if the quality of the effluent obeys the standards. However, not all industries can achieve compliance standards [26] and this encourages the necessity of enabling the industrial effluent for the recycling of industrial water. Furthermore, The Government of India has proposed to develop a framework in the National Water Mission (NWM) to enhance water use efficiency by 20%.

A similar situation is experienced in China, where due to rapid development and industrialisation in the past decades, the industries are able to freely discharge their wastewater into lakes and rivers due to poor environmental regulations, weak enforcement and local corruption[27]. The discharge of industrial pollutants into the water cycle has caused increasing concerns for Chinese citizens and policymakers [27], [28]. The Environmental Protection Law in China was tightened in April 2014 to address this issue and coupled with the public's higher environmental awareness, this acted as a trigger for the various industries to challenge themselves in seeking different approaches to increase industrial water efficiency, including appropriate wastewater treatment technologies and water reuse practices [29].

3.2.4. Water Reuse As An Emerging Solution

As discussed in Section 3.1, industrial processes require water, with indications of increasing demand and cause a reduction in the availability of water for the environment or other processes, or alternately contaminate and release water that damages the local environment. In order to address these issues, several measures are listed in the European Commission's Communication 'A Blueprint to Safeguard Europe's Water Resources', including water reuse. Compared to alternative water supply such as desalination which requires a huge amount of energy, water reuse may have a lower environmental impact [30], [31].

Near Zero Liquid Discharge (ZLD) is a concept that encourages recycling and reuse of industrial wastewater through a process or combination of processes with the aim of no liquid effluent discharges into the surface water. Through AquaSPICE's pillars, the industry will be able to demonstrate various techniques that concentrate the effluent using advanced technologies and processes to recycle industrial wastewater as a clean stream for re-use, thereby reducing freshwater abstraction and use and enhancing industrial water efficiency [32]. Furthermore, the integration of digital technologies into the monitoring of water networks will help to achieve greater transparency into water quality [33].

3.2.5. The Shift Towards Industry 4.0/5.0

Digital technology offers enormous potential for enabling solutions to address complex shared water challenges and this is an opportunity which AquaSPICE will explore and exploit for an improved water efficiency in the process industry. In the industrial sector, digitalisation has revolutionised the sector, making the industries more connected with their processes via newer pathways of optimisation and process efficiency to be more competitive and sustainable. Industry 4.0 is the transformation of modern society and economies through innovation via the advancements in digitalisation, interconnectivity, data analysis and automation. Increasing digitalisation will have a decisive impact on the business models of the process industry. The technological elements of Industry 4.0 (Industrial Internet of Things (IIoT), Cyber-Physical Systems (CPS), Cloud Computing, Edge Computing, Big Data Analytics and Artificial Intelligence (AI) and Machine Learning) will integrate and create an information-centric and connected workforce [34]. However, Industry 4.0 is not the end of the road, the trends and evolution of data interconnectivity have discovered newer methodologies for improving the industrial and manufacturing ecosystem (Industry 5.0) as illustrated in Figure 3 below.

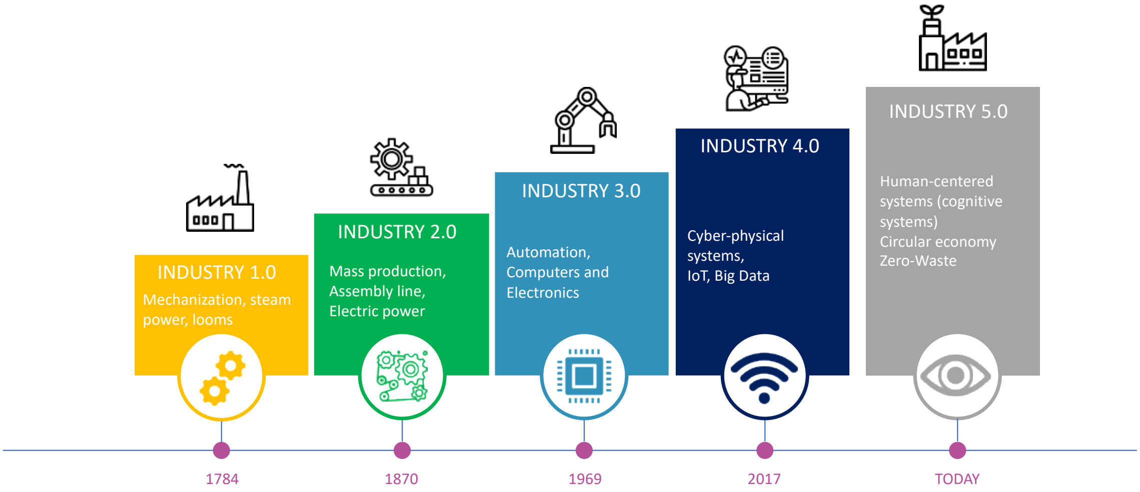

Figure 3- Evolution of Industry

A paradigm shift to industrial sustainability and circular economy, enabling the materials and resources to be reused between processes and industries. The impact of these strategies focuses on strengthening the interrelationships between companies and also, reducing the production costs while reducing negative impacts on the environment. In this regard, digital systems are moving from process control automatically towards autonomous systems capable of self-learning and self-adapting. Another important key aspect is the importance of workers and the development of digital tools to improve their skills while acting autonomously over the industries.

Industry 4.0/5.0 and AquaSPICE synergise and utilise networks of sensors installed through industrial water abstraction, process, treatment and recycling operations, with the aim to unwanted variations in the production-based industry [8]. This full digitalisation of all operations will monitor conditions in real-time to connect and detect non-optimal water use and foster water-saving awareness, creating a quantum leap in the productivity, flexibility and quality of the operation, leading to an agile and adaptable industrial water efficiency system.

3.2.6. Industrial Symbiosis and Fostering Collaboration Network

The idea of industrial symbiosis is to redirect surplus resources (by-products or the conventional waste in the industrial process) and use them as an input into other processes, realising mutually profitable trades for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes [35]. Industrial symbiosis is a huge opportunity for AquaSPICE as the project aims to explore and exploit treatment of the 'used' resources (i.e. wastewater) to make them fit for a new purpose then unlock the value embedded in these underutilised resources, for instance, redirecting a process contaminated water stream to a nearby biogas plant where it is used as a 'new' input into the production process [7], [36].

Given the nature of establishing a water reuse and sharing efficiency scheme and industrial symbiosis, bridging treated water and other by-products (resources) means developing new partnerships between business owners and external agencies and stakeholders.

This partnership is highly interconnected and can provide a networking opportunity for the industries through collaboration. When a cross-industry water efficiency scheme is discussed, it presents a platform to communicate water-related impacts and dependencies between the parties. This collaboration will also help the sectors respond to the growing demand for water in a sustainable manner, which traditional management cannot provide. This unique stewardship will enable all actors in the value chain to collaborate to solve both current and future water-related challenges.

3.2.7. Reducing Cost, Water Consumption and Environmental Footprint in Industrial Practices

The industry is a major water user and has a huge influence on local water consumption. Traditionally, centralised large wastewater treatment plants were designed as the sole option to accommodate all the wastewater streams across the municipality, including industrial wastewater. This results in a high capital cost required to build a large-scale centralised wastewater treatment plant [37].

A study has presented that up to 90% of the generated wastewater amount can be treated on-site to meet the water standard for process water uses [13], [38]. Furthermore, achieving efficient water use in the process industry could add economic value from wastewater resource recovery. Depending on the nature of the process industry, industrial wastewater can be a great source of sustainable energy and resources. This is beneficial not only for the societal transition to a circular economy but the economic price of these by-products can contribute to offsetting the operation cost of the industry.

The advancement of digital technology also helps to build the business case of a smart water network which could bring various financial benefits [33].

3.3. Gaps and Barriers

3.3.1. Lack of Awareness and Understanding of the Benefits of Water Recycling

The first challenge in dealing with circularity in the process industry is to understand it. A lack of understanding of water issues in general, and the opportunities that water reduction, reuse and recycling practices present at industrial levels hinder projects to reuse and recycle water [39]. While industrial water reuse provides various benefits, these benefits are not easy to be quantified and represented [40].

There is a lack of structured public awareness engagement focussing on industrial water recycling, especially related to different industrial sectors, countries or cultural settings. Conversation among industries, governments and other water users at the watershed level is still not common practice [39].

3.3.2. Bridging Reclaimed Wastewater Supply and (Quality) Demand

Treated industrial wastewater can be reused onsite, or between other businesses or sectors by means of an exchange scheme or industrial symbiosis. Reusing this resource brings many benefits, however it comes with different challenges related to the volume, type and quality of the wastewater [41]. In practice, it is not easy to put this concept into action. The quantity of effluent discharge varies depending on the operation, start-ups and shut-downs, working-hour distribution, seasonal effects and so on. Furthermore, industrial wastewater comes in different qualities and strength depending on the nature of the business, some examples of this is shown in Figure 4 [42].

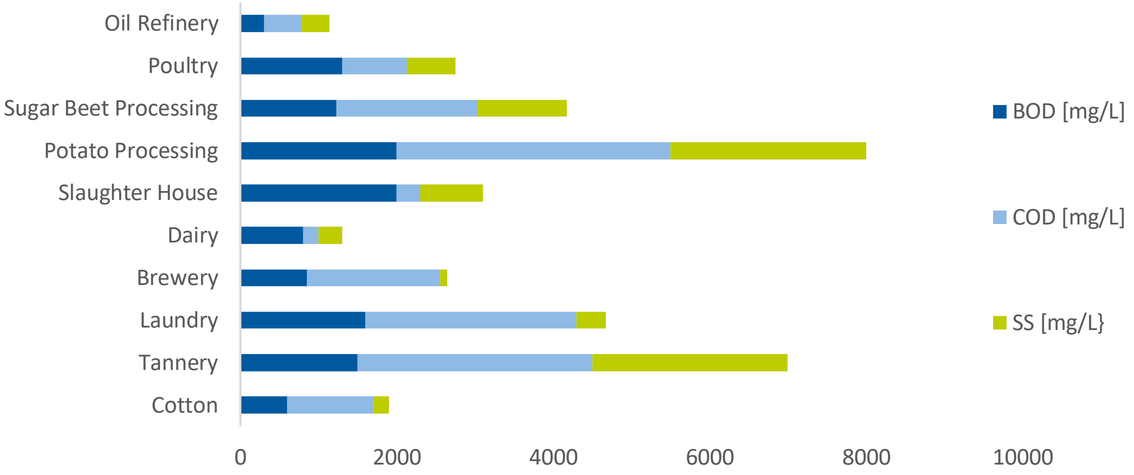

Figure 4- Strength of wastewater comparison in terms of BOD, COD and SS from different industries [42]

Industrial wastewater also contains industrial-specific pollutants such as lead, mercury, nitrates, phosphates, sulphur, oils and petrochemicals in different concentrations which pose a technical challenge when it comes to removing these pollutants for a safe effluent reuse quality.

For most industries, there are strict conditions in the quantity and quality of water used in its operation. The same requirements have to be applied when employing recycled water in the operation. The information and data are crucial to facilitate and encourage the use of recycled water but these data are not readily available. As mentioned earlier, industrial wastewater is usually heavily polluted and opportunities for direct reuse are usually limited. Additional treatment or source control usually has to be applied to match the process needs [43]. Furthermore, if the water is to be used as material for industrial symbiosis, the availability of information may be restricted by companies' confidential agreements. All these factors are crucial for any industry and could hinder the progress in encouraging industrial circularity as a constant non-interrupted flow of (reclaimed) wastewater throughout the operation [13], [26], [44].

3.3.3. Institutional Inertia and Lack of a Supportive and Coherent Framework for Water Reuse

While the 12th Sustainable Development Goal (SDG) supports the more efficient use of natural resources such as water and targets to achieve the sustainable management and efficient use of natural resources by 2030 [45], the lack of a supportive coherent framework to encourage the industrial water reduce and reuse scheme is a barrier to be addressed. While a series of regulations, standards and guidelines (see Table 1 below) has addressed the need to reduce water abstraction and encourages the idea of circularity of water, little attention has been paid to clear directions, aims and performance indicators in industrial water reuse standards. The guidelines are often targeted at water reuse for other purposes such as irrigation and aquifer discharge. For example, the Urban Wastewater Treatment Directive (UWWTD) urges member states to reuse treated water "whenever appropriate", but there is not a structured and clear indicator of the levels of "appropriateness" in this directive. Moreover, the directive's scope mainly focuses on a limited amount of industrial sectors (refer to Annex III of the Directive). On the other hand, the European Parliament and Council approved the new EU Regulation 2020/741 on “minimum requirements for water reuse”, while the directive has provided different reclaimed water quality classes and their permitted uses, the applicability of the minimum reclaimed water quality class is only referred to agriculture uses.

Directives and Guidelines	Comment
Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy [46] or Water Framework Directive (WFD)	European Union's flagship Directive on water policy to manage and protect water bodies. It provides measures to improve water efficiency and reuse and promote water-efficient technologies in the industry. It sets up the basic measures to promote efficient and sustainable water use and controls the abstraction of fresh surface water and groundwater This Directive also is a governance structure set up for the integration of water management and pollution reduction in the water cycle. Article 9 of the Directive requires implementation of pricing and cost recoveries policies that provide an incentive to use water efficiently.
Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption [47] or Drinking Water Directive	This Directive concerns the water quality required for the food processing industry and drinking water.
Council Directive of 21 May 1991 concerning urban waste water treatment (91/271/EEC) [48] or Urban Waste Water Treatment Directive	This Directive concerns the treatment and discharge of wastewater from certain industrial sectors to ensure the environment is protected from the adverse effects of wastewater discharges. The Directive defines industrial wastewater and requires treated wastewater to be reused whenever appropriate.
Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste [49] or Waste Framework Directive	This Directive establishes the legislative framework for the handling of waste in the Community. The directive aims to improve the efficiency of resource use and ensure waste is valued as a resource by improving waste management operations. The Directive provides definitions of waste and extended producer responsibility scheme also encourages the replicable practices of industrial symbiosis and circular economy model through the recognition of by-product as a resource.
Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse [30] or	This Regulation aims to enable water reuse whenever it is appropriate and cost-efficient, however focuses on the safety and requirements of reclaimed water for agricultural irrigation. The regulation’s definition of ‘reclaimed water’ only focuses on urban wastewater per the UWWTD and does

Directives and Guidelines	Comment
Water Reuse Regulation	not have coverage on industrial wastewater. The Water Reuse Regulation lays down the key elements in the water reuse risk management plan and subsequently the reclaimed water permit obligations.
Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) [50] or Industrial Emissions Directive	This Directive lays down rules to prevent or reduce industrial emissions into the environment and to prevent the generation of waste in the industrial process to achieve a high level of environmental protection. The Directive encourages establishing a general framework for the control of main industrial activities, utilising the 'polluter pays' principle and the principle of pollution prevention. This Directive also introduces the Best Available Technologies (BAT) comprising the criteria for determining the best available techniques such as reduce the abstraction of natural resources including water.
Regulation (EU) No 2150/2002 of the European Parliament and of the Council of 25 November 2002 on waste statistics [51] or Waste Statistic Regulation	Regulation for constructing Community statistics on the generation, recovery and disposal of waste. The Regulation listed the requirement for transmitting and reporting data including • water collection, treatment, supply and disposal into a water body • sewerage • sludges from industrial waste • waste from cooling tower treatment • sludges from biological and other treatment of process water and industrial wastewater
A Blueprint to Safeguard Europe's Water Resources [30], [31]	Blueprint to strengthen the need to create an instrument to regulate standards for water reuse, explore alternative water supply options to reduce water scarcity and lessen the negative impacts on water status.
A new Circular Economy Action Plan For a cleaner and more competitive Europe[52]	This action plan introduces a new EU industrial strategy that encourages the green and digital transition of the EU industry. Further support circularity through promoting the use of digital technologies for tracking, tracing and mapping of resources. This action plan sets up to review the current directives on wastewater treatment and sewage sludge, and also to facilitate water reuse and efficiency, including in industrial processes.

Table 1- Relevant EU policy guidelines to identify the gaps and barriers towards the development of an enhanced water efficiency framework in process industries [30], [31], [46]–[52]

As shown in Table 1, there has not been any short, medium or long term recommendations or guidelines addressing the exchanges of water and other resources between different industries or sectors, in some instances these exchanges are not direct and cannot legally be exchanged. Hence the lack of specific agreement could be a huge barrier when managing supply and demand especially about the quality and quantity of the treated wastewater, ultimately placing the environment and/or public health at risk [53], [54]. Intervention and negotiations are needed from various perspectives, with agreements involving regulatory authorities may be needed [55].

In some cases, the lack of reliable and standardised data (transparency) in industrial water management does not give confidence to the public and stakeholders. A standardised control and monitoring strategy were not developed or covered by any national strategy and policies, the inconsistency could lead to failure in control and monitoring [43].

The true values and costs (financial and social) of water reuse projects have never been properly evaluated [40]. The lack of a coherent framework that quantifies the true value embedded in the industrial circular water approach, such as loosen the water stress by reducing demand on the freshwater source, lessen the discharge of pollutants into the environment and reducing centralised wastewater treatment and disposal costs, could be quantified [56].

3.3.4. Lack of Accurate Estimations and Definitions of Water Use by the Industries

While there is an established body of research on water use by the domestic and agricultural sectors, there is very little peer-reviewed literature focusing on industrial water use, hence data and information regarding the amount of wastewater produced by industry are very deficient, especially in a clear and transparent manner[2]. The definition of 'industrial water' often varies between different parties, especially in defining water use in the process industries. Whether the water is used as a raw product, water use associated with only the process unit operations, the water footprint of cleaning and transportation or the virtual water entrapped in the product, there are no common standards in defining the boundaries. Furthermore, there is a gap in the data management activities, data is gathered and stored but poorly managed due to the considerable efforts of data governance [57]. This will be a continuous issue as the volume of data to be processed will grow at a rapid pace in the future.

In an ideal world, all water data would be obtained by direct measurements. However, this may not be the case. The process of gathering data is often from facilitated initiatives such as surveys or questionnaires that have different protocols and different definitions. This data is often fragmented, inconsistent across initiatives and time, hence difficult to validate. For example, a water statistic carried out by the statistical office of the European Union, Eurostat does not define the discharges from cooling water as wastewater, and this may differ from other datasets when no clear definition, methods and procedures of how these data were gathered [4]. Furthermore, the estimation of water reuse volumes is also associated with high uncertainties because there has not been a standardised interpretation of what should be officially reported as 'water reuse'. Therefore, a novel framework that attempts to standardise and aggregate the information and clarify these ambiguities is beneficial to provide a greater understanding of the water use by the industry, thus untapping the further potential embedded in the industrial water.

3.3.5. Development of a clear process-circular-digital integrated technology solution

The advancement in technology is undoubtedly one of the strongest factors shaping the industrial landscape today. The first step towards an integrated technology solution is the accessibility to the technology. Not all countries are equal in terms of development. Very often, a country's development status is proportional to the degree of industrialisation relative to their populations. Less developed countries sometimes do not have reliable access to integrate new technology into the existing system, and even if they do, high capital investment is usually required for such integration. Moreover, the upgrade, implementation and operation of a conventional system to a process-circular-digital integrated solution require technological expertise. Due to the rapid evolution of technology, continuous adequate professional development and training are required to keep their skills current for these activities. Furthermore, the development of a clear process-circular-digital integrated technology solution is unique for different situations and the process can be time-consuming.

3.3.6. Economic Price of Water

While reducing water consumption generates various benefits, the additional benefits linked to the "value" and "cost" of water are usually underappreciated. In many parts of Europe, the water price is subsidised, resulting in the industries, agriculture and household users paying less than the total cost of supplying and using it. This encourages inefficient water use as such ineffective water pricing policies do not usually reflect the depletion of water resources at a local level.

While the industries might have a positive attitude towards advancing circular water use in the industries, the industries' willingness to pay for reclaimed wastewater is usually relative to the current price they are paying for alternative water sources and inclined towards paying less amount of money than they already pay for the same amount of freshwater as additional CAPEX and OPEX have to be considered to enable an enhanced water efficiency plan such as additional treatment units and operations [43]. This additional cost causes the return on investment (ROI) on circular water management to be undervalued because freshwater is cheap [39]. Figure 5 shows the public supply water prices in selected major cities taken in the year 2009 expressed in US dollars per cubic metre supplied [58]. If freshwater was charged at a price that truly reflects scarcity, it will be more expensive and hence the value of the wastewater reusing schemes will be appreciated more.

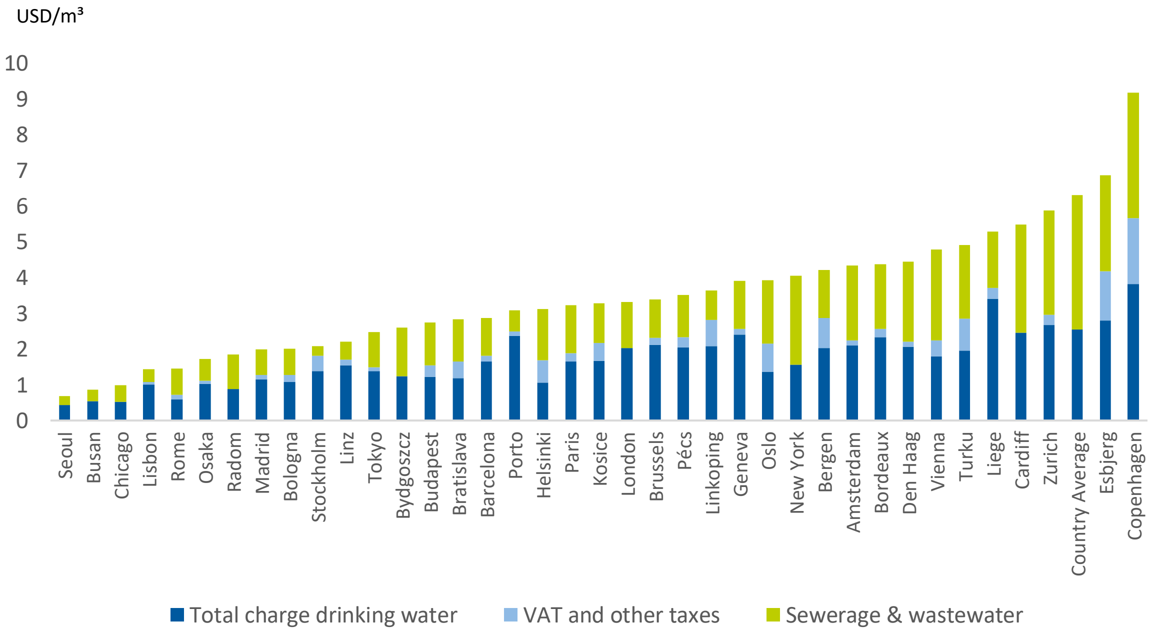

Figure 5- Public water supply price comparison for selected major cities [58]

Apart from directly incurred costs, social costs and social benefits are often ignored evaluating this type of project. The evaluation often compares only the financial costs and does not quantify either social costs or social benefits associated with industrial circular management. However, this is not always easy to quantify. Whilst recycled wastewater has an economic value, the nature of water is both a public and private good under different contexts and makes it difficult to differentiate and price its market and environmental value [59]–[61].

3.3.7. Public and Stakeholders' Perceptions

Public and stakeholders' perceptions act as one of the main barriers for any water reclamation, recycling, and reuse scheme [40]. This situation complicates for any reuse scheme to be financed, developed and operated [62].

Although treated wastewater has achieved the quality required for reuse via the development of suitable technologies, the general public is still biased towards the 'naturalness'- for instance, industrial wastewater is often perceived as an undesired leftover of industrial production and often associated with a wide number of questions and problems [37], [40]. A few surveys carried out showed public associated the idea of reusing wastewater with a few social stigmas. Most are open to the idea of water that is discharged from a wastewater treatment plant and released into the environment- the river, then being redrawn again as this is being depicted as 'natural' as compared to treating and reusing the water on-site [40]. This difference in perceptions could be due to a lack of such information and transparency being provided to the public and stakeholders. A few other psychological variables that associate public perceptions on reuse of wastewater scheme are summarised in Table 2 [10], [63]–[65].

Public's Psychological Factors Associated with Wastewater Reuse Scheme
Emotion: Positive or negative emotions towards wastewater reuse scheme
Subjective Norm: Pressure and influence from other people to support the scheme
Fairness: Personal evaluation on whether the scheme is fair to the environment and other users
Other: Trust towards authorities, available information and past experience with alternative water sources

Table 2- Summary of Public perceptions towards wastewater reuse scheme obtained from past surveys [8], [63]–[65]

Public and stakeholders' acceptance of water recycling is associated with high emotive perceptions and these perceptions on wastewater reuse can be measured in [66], [67]:

- Willingness to Use: Acceptability of wastewater reuse scheme directly or indirectly
- Willingness to Pay: Acceptability to pay for reusing wastewater or alternative sources such as rainwater

Although both Willingness to Use and Willingness to Pay are associated with the quality of treated wastewater (the level of treatment), other circumstances such as water stress, and stronger environmental awareness also influence the public's perception towards wastewater reuse scheme [67]–[69]. The economic price of freshwater is a strong influence on the public Willingness to Pay for reusing wastewater.

Hence, decision-makers often have to address negative public attitudes toward reusing wastewater for some specific purposes [13].

3.3.8. Quality of Water and Wastewater Technologies

The introduction of water reuse advances the circularity of the water cycle, closes the loop and provides an alternative water source. With adequate treatment, wastewater is able to replenish water supplies and reduce the demand and availability gap, especially in the water-stressed region.

To ensure the quality of treated wastewater fits the requirements for its reuse purpose, the selection of wastewater technologies is essential to advanced water quality, safety and suitability for the specific reuse applications [43], [70]. For example, the requirements are the strictest (drinking water standard) for process water in the food industry as laid out in the Drinking water Directive, thus the selection of technologies and treatment flowsheet is rather complex to ensure that the treated water for reuse is fit for purpose [47], [71], [72]. Section 5.2 considers and discusses the various advanced water treatment technologies.

3.3.9. Challenges of Digitalisation

While digitalisation of the process industries could advance sustainability, it does come with added challenges such as cybersecurity, and the impact of a cyber-attack could be severe; some possible impacts include a financial loss due to disrupted production and harm to people or the environment due to the threats in technical infrastructure [8], [73]. An example is a case in Queensland, Australia, where the SCADA system of a water utility was accessed by a displeased employee and released 800,000 litres of raw sewage, causing environmental and economic damages [74]. While it remains a threat, this is common with all individuals and organisations with a connection to the internet, and not just limited to the process industry. Another challenge of industrial digitalisation is the lack of quantity or quality data for process automation, data governance and price of data management solutions [57]. These will be discussed in Section 5.3 of this report.

3.3.10. Economic feasibility of investments and financial incentives

The cost associated with building a brand new or upgrading an existing system (process and digital) is one of the many important barriers to the enhancement of water efficiency in the European process industry, this covers the capital cost (CAPEX) and operation cost (OPEX) of the treatment facilities. A tailored, detailed cost estimation will not be covered in this report as the cost estimation has many components and is highly dependent on the accuracy to the level of detail of the project, which is not readily available at this stage of the project. Instead, an overview on the costs, using cost functions, of the existing treatment technologies is highlighted. These cost functions are typically used for preliminary cost estimations and were built by calculating the arithmetic function of the individual cost from the literature [75]. While the functions have some limitations due to the underlying database and are built based on several assumptions, they are sufficient to estimate the cost of the individual treatment process. As shown in Figure 6 and Figure 7, the modular cost functions developed by Hilbig et al. (2020) have estimated the treatment cost of several processes in €/m^3/d and €/m^3 based on the wastewater flowrate or volume. The model presents a lump sum estimation based on the wastewater capacity and types of treatment. Figure 8 compares cost estimation of conventional activated sludge (CAS) systems and membrane bioreactor (MBR) systems extracted from Brepols et al. (2010), MBRs typically have lower construction cost compared to CAS but the additional cost has to be considered for membrane operation and replacement [76]. Alternative cost estimating methods are summarised in Appendix I: Different Cost Models Used in Literature for Cost Estimations [77].

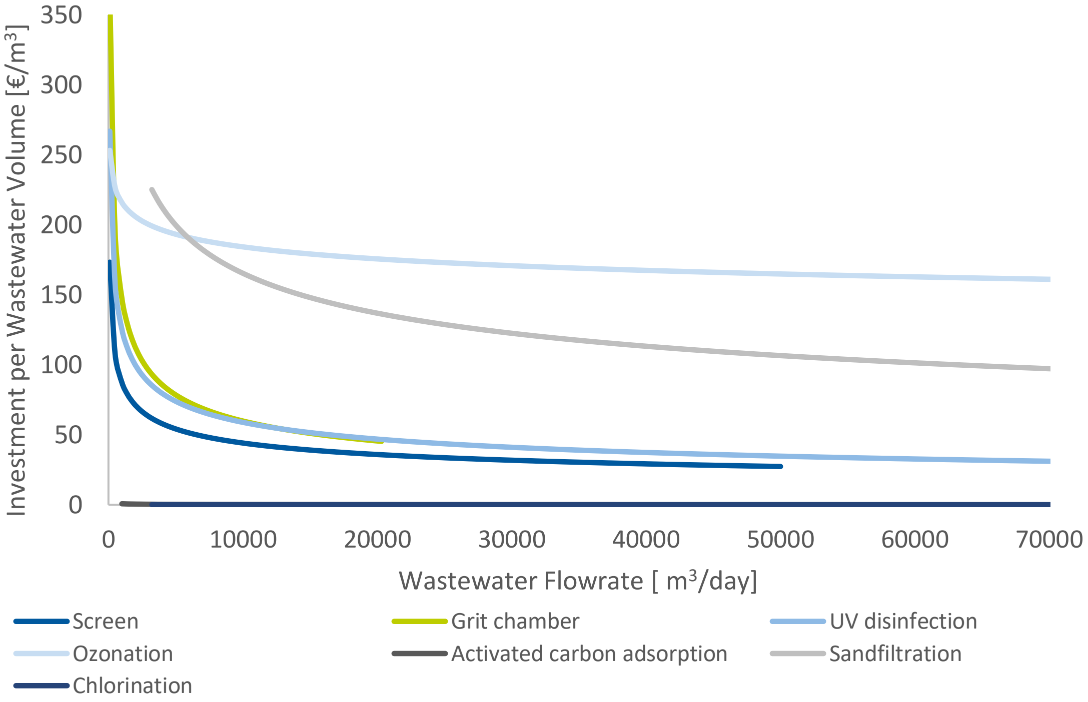

Figure 6- Treatment processes cost estimation per wastewater flowrate

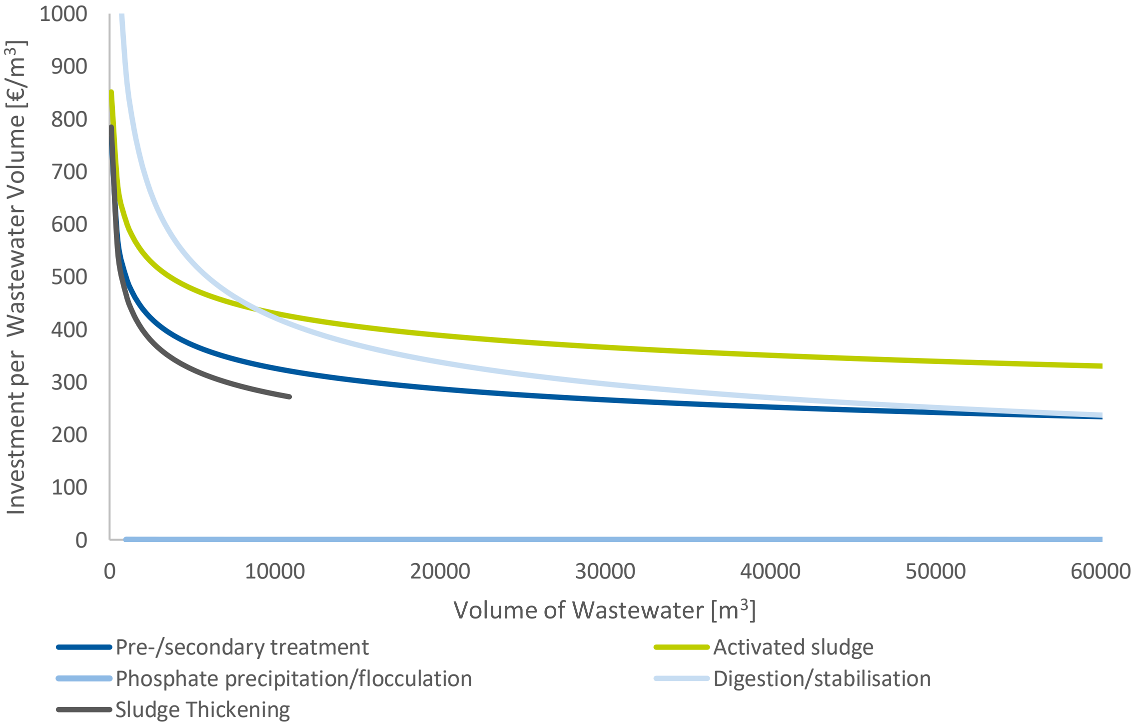

Figure 7- Treatment processes cost estimation per wastewater volume

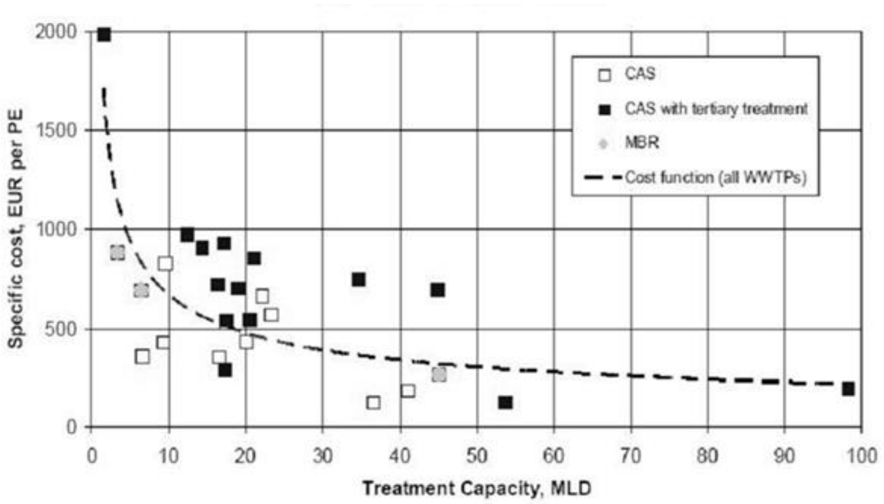

Figure 8- Cost comparison of CAS and MBR systems extracted from Brepols et al. (2010)

The detailed breakdown of CAPEX and OPEX which is outside the scope of this Task will not be covered in this deliverable as it significantly varies with optimisation of the typical cost considerations of (waste)water treatment plants, which are summarised in Figure 9 [78]. Very often, these high investments to upgrade the system are expected to have a life cycle of at least 20 years and it is difficult to gain access and secure an upfront investment for sufficient funds [33], [65]. Additionally, the lack of resources to sustain any sort of operational subsidy means that systems must be largely designed to be financially self-sustainable.

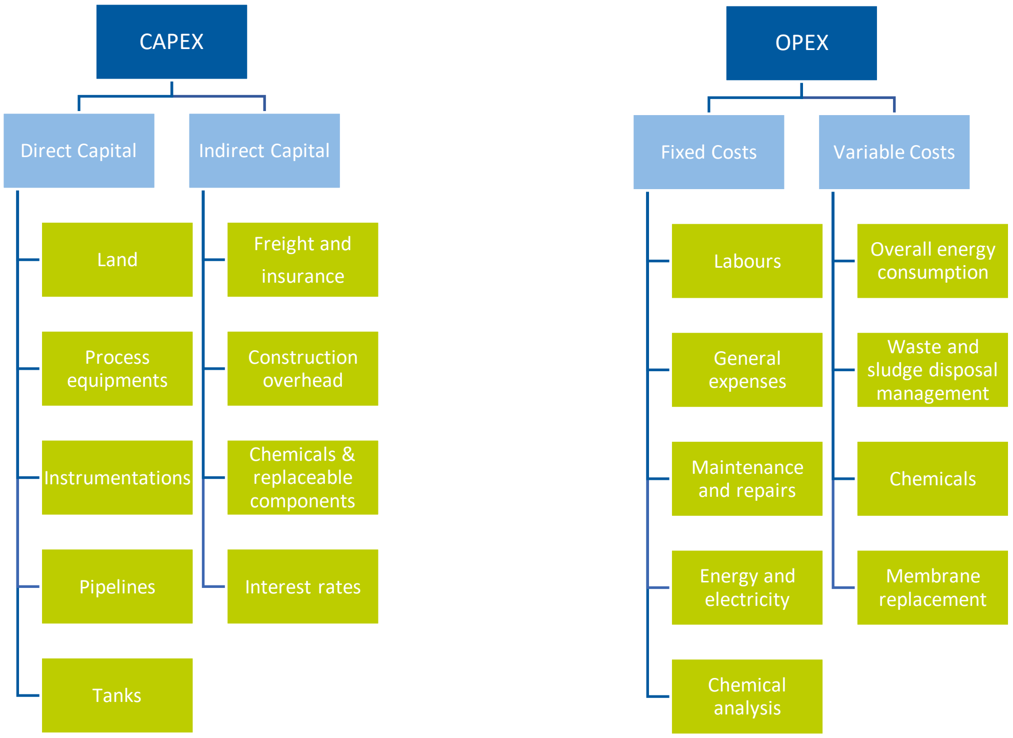

Figure 9- Key CAPEX and OPEX components of a wastewater treatment facility

3.3.11. AquaSPICE Approach to Address Gaps in an Industrial Water Efficiency in the European Process Industries

In the previous section of the report, the gaps to materialising circular water use in the process industries have been identified. These gaps and barriers are further categorised into 4 areas of consideration, namely technical, legislation, social and economic. Table 3 presents a matrix of the gaps, specific action steps within AquaSPICE in order to close these gaps and achieve the proposed goals of enhanced water efficiency in the process industries.

Areas for Considerations	Main Gaps and Barriers	AquaSPICE's Exploration of the Possible Solutions/Measures to Address These Gaps
Technical	Lack of a clear structured methodology in assisting the selection of the optimal fit-for-purpose technologies and the configurations for water treatments and resource recovery that is based on considerations of critical indicators when measuring water efficiency measures along with a reduction in energy consumption. Lack of integrated methodologies and advanced model-based tools to assess industrial water re-use practices and accurately determine the costs and benefits from a life-cycle perspective. Lack of available data in industrial water usage thus methodologies and tools to assess and monitor water symbiosis. Lack of interoperability and data sharing between the industrial processes to distil symbiotic pathways at local and wide-scale. Limited proven examples of a process-circular-digital integrated technology solution in managing industrial wastewater streams. General lack of flexible and robust monitoring systems to enable an adaptable water CPS to support holistic water management schemes along with a shift towards industrial 4.0.	AquaSPICE will be developing a water efficiency framework for enhanced water efficiency [Deliverable 1.6: Water Efficiency Applications Framework for the Process Industry] and assessment and optimisation procedures incorporating a common data exchange model (ontology) to interrelate processes and operational measurements for enabling a common understanding of the information [Deliverable 1.5: Data Models, Taxonomy and Ontology Industrial Water Use] and explore the possible incorporation of case studies and future data into a common interoperable model. AquaSPICE will generate a list of parameters to define the evaluation process of technologies and industrial practices [Deliverable 2.2: Technologies and Practices Evaluation Framework], these parameters will be employed in the case studies and the results will be compiled into technology data, case factsheets, legal/regulatory, and economic aspects. These data will then be a part of the services and integrated function model of the water CPS platform to analyse the interfaces, specifications, and information flow among all modules/ components. This information will be collected and presented into an adaptable dashboard to look into different functionalities of the components [Work Package 4: Digital Twin with Smart Analytics and Cognitive Services for Water Efficiency & Work Package 5: Water Cyber Physical System: The Industrial Water Efficiency Management System].

Legislation	Lack of a clear structured European policy and guideline targeting industrial water efficiency. Need for a comprehensive review of the existing legislative framework specifically looking into industrial water efficiency and local permitting restrictions. Lack of infusion of industrial water symbiosis scheme issues in water policies, taking into consideration different industrial water management standards (i.e. stringer standards for the food industry).	AquaSPICE will look into current European policies, regulations, and standards [Deliverable 7.10: Final Report on European Policies and Industry Recommend] to provide recommendations for the technical, organisational, and regulatory framework and guidelines towards the novel water efficiency framework. An attempt will be made to use these regulatory recommendations as a reference when developing consensus-based standard processes with a link to existing water and industrial standards.
Social	Lack of awareness and understanding of the benefits of water recycling causes negative perceptions or perceived public health and safety concerns on water reuse. Lack of education or awareness in the industrial practices of the benefits of efficient industrial water use. Lack of confidence in the scheme due to limited availability of evidence that demonstrates the successful application of such schemes.	Based on the results and findings, AquaSPICE will generate dissemination materials [Work Package 8: Communication, Dissemination, Training and Social Awareness] to the general public in conferences and events to raise awareness and understanding of the benefits of an efficient industrial water scheme.Based on that, a curriculum can be built and the course material developed can be integrated into existing curricula [Task 8.4: Training, Education and Lifelong Learning].
Economic	Lack of business models and service concepts to support industrial collaboration in water symbiosis. Difficulty in mapping supply and demand of treated wastewater of various quality may cause inefficiency or extra wastage. The low economic price of water and a lack of a cost calculator to assess the true cost of water taking into account indicators such as (water footprint and embodied energy.	An online platform will be developed to map the water/wastewater streams in a given geographical region [Deliverable 2.4: Enabling Platform for Water Symbiotic Schemes], then propose alternative solutions for wastewater reuse, and finally to evaluate the economic feasibility of the proposed solutions, based on the economic output of each involved stakeholder (source and receiver of the wastewater). The project will also create a space to carry out stakeholder engagement activities [Deliverable 1.2: User Analysis, Use Cases Requirements, and

	Lack of investments and financial incentives/ subsidies to support the partnership opportunities to promote industrial water efficiency scheme.	Quality Criteria] and will allow more targeted conversations and collaborations to be formed. These inputs will be fed into the aforementioned online platform. AquaSPICE will assess its solutions' market potential via surveys about the interest of industries in Europe [Deliverable 7.1: Market Analysis and Strategic Plan for Uptake, Replication & Upscale]. Predicated on that, the replication potential for AquaSPICE solutions will also be evaluated. Related financial schemes will be developed along with new business models for the delivery of the solutions. Lastly, exploitation plans can be established incorporating the definition of product and services, market and competitor assessment, and the strategy to implement the services between partners including start-up, spin-off and joint venture [Work Package 7: Solution Uptake, Replication, Up-Scaling and Exploitation].

Table 3 - Matrix of the main gaps in water efficiency enhancement in the process industries and AquaSPICE's approach to addressing these gaps

4. Synergies with Previous Horizon 2020 (H2020) and SPIRE (The Sustainable Process Industry through Resource and Energy Efficiency) projects

Previous EU project, namely Horizon 2020 (H2020) and SPIRE (The Sustainable Process Industry through Resource and Energy Efficiency) synergise with AquaSPICE where key transferrable knowledge will be considered and explored for implementation in AquaSPICE use cases.

H2020 is the biggest EU Research and Innovation programme to make breakthroughs, discoveries and world-firsts by taking great ideas from the lab to the market. AquaSPICE is a part of the programme under the subtopic 'Preserving fresh water: recycling industrial waters industry', the projects under this subtopic look into near-zero discharge using closed-loop systems in combination with recovery of energy and/or substances (resources) through the development of integrated water-smart strategies for industrial processes[79]. These closed loops would significantly reduce the use of fresh water and improve water availability thus align with the guidelines outlined in the Water Framework Directive (see also Section 3.3.3).

AquaSPICE is also under the SPIRE calls. SPIRE is a proposal driven by the European Process Industry and associated with the strategic goals defined by the European Commission in the Europe 2020 strategy [80]. The SPIRE projects aim to rejuvenate the European process industry, make it more competitive and sustainable, and lead to European growth and jobs. One of the key areas for development under the programme is to optimise and integrate the re-use of water in the process with key enablers such as water symbiosis and delivery of fit-for-purpose water through treatment. The model of Industrial (water) Symbiosis can become a relevant tool to get closed water cycles in or around industrial parks with the aid of digital systems and tools such as including in-line monitoring for assessment and control of quantity and quality [81]. Under the H2020 umbrella, there are a total of 584 water related H2020 projects and among these, around 100 projects (refer to Appendix III: Relevant H2020 Projects) have some relevant information related to the process industry or aligns with AquaSPICE's objective of enhancing circularity of water use.

Table 4 summarises a few projects from H2020/ SPIRE with transferable knowledge/outputs that are valuable in helping to construct the holistic water management framework in the later stage of the AquaSPICE project. The key transferable concepts are summarised under the column 'Related Concepts'.

Project	Project Group	Short Description and Transferable Knowledge	Related Concepts
AccelWater https://www.accelwater.eu/	H2020 SPIRE	AccelWater's project main objective is to optimize freshwater water consumption in the food and beverage industry under a water-waste-energy nexus by introducing beyond state-of-the-art water reclaiming, reusing and Artificial Intelligence enabled monitoring and control technologies that will permit the use of reclaimed water in the manufacturing processes	Water reuse – energy – carbon nexus; Innovative AI for reusing/recycling water; Waste and energy reclamation

Project	Project Group	Short Description and Transferable Knowledge	Related Concepts
		of food and beverages and on the same time will allow waste and energy reclamation, optimization and management, and consequently will result to environmental and socio-economic sustainability.	
B-WATER-SMART https://b-watersmart.eu/	H2020	H2020 project devoted to demonstrating a tailored suite of innovative technology and management solutions for key sectors with a high turnover of water and other resources.	Business Models; Recycling and reuse water technologies; Real-time monitoring and control
CAPRI https://www.capri-project.com/	H2020 Spire	CAPRI works towards the digital transformation of the process industry through an innovative Cognitive Automation Platform (CAP) encompassing methods and tools of the six Digital Transformation pathways (6P -> Product, Process, Platform, Performance, People, Partnership), engaging the cognitive human-machine interaction It further develops a toolbox of cognitive solutions for planning, operation, control and sensing. CAP Platform and the cognitive tools included can be replicable in areas of production planning, control, automated processes and operations of all SPIRE sectors.	Cognitive Twins; Dynamic Optimisation; IOT
COCOP https://cocop-spire.eu/	H2020 SPIRE	This project aims to define, design and implement a concept that integrates existing industrial control systems with efficient data management and optimisation methods and provides means to monitor and control large industrial production processes.	Digital solutions for water management; Data Driven Analytics
COGNIPLANT https://www.cogniplant-h2020.eu/	H2020 SPIRE	Process industries turn to advanced technology to improve production and quality control and limit unplanned negative occurrences. Advanced data control and analysis combined with the Digital Twin concept offer substantial benefits to production plants. COGNIPLANT will increase operation performance, boost quality control of the final products, speed up response time to unplanned incidents and reduce CO_2 emissions	Cognitive platform, Digital Twins; Process Optimisation

Project	Project Group	Short Description and Transferable Knowledge	Related Concepts
COGNITWIN https://www.sintef.no/projectweb/cognitwin/	H2020 SPIRE	This project will partner with numerous industries and research groups from around Europe to create a platform that includes a sensor network for monitoring and collecting data from various plant processes	Data driven analytics; IOT; Real time monitoring
CoPro https://www.spire2030.eu/CoPro	H2020 SPIRE	The goal of CoPro has been to improve the energy and resource efficiency of industrial plants and industrial parks by improved process monitoring and optimal dynamic planning, scheduling and control of interconnected process units and plants, thereby making significant contributions to reduce the carbon footprint of the European process industries.	Real time process monitoring and control; process optimisation; Data driven analytics
DWC https://www.digital-water.city/	H2020	H2020 project dedicated to the digital transition of urban water management. It aims to create linkages between the digital and the physical worlds by developing and demonstrating various advanced digital solutions to address current and future water-related challenges	Water reuse – energy – carbon nexus; Digital solutions for water management
E4WATER	H2020	Primary contribution of E4Water includes a paradigm shift in chemical industry to create a breakthrough in industrial water treatment and management. The project has addressed crucial process industry needs to overcome bottlenecks and barriers for an integrated and energy efficient water management.	Recycling and reuse water technologies, Process Optimisation
FACTLOG https://www.factlog.eu/	SPIRE	SPIRE project that aims to enhance energy and resource efficiency in process industries by combining resource-aware optimisation with the virtualization of production processes based on the interplay between enhanced cognitive twins and real-time analytics.	Digital Twins; Cognitive Twins; Machine Learning & Data Driven Analytics; Dynamic Optimisation
FISSAC http://fissacproject.eu/en/	H2020 SPIRE	The FISSAC project involves stakeholders at all levels of the construction and demolition value chain to develop a methodology and software platform, to facilitate information exchange, that can support industrial symbiosis networks and replicate pilot schemes at local and regional levels. The model will be based on three sustainability pillars: Environmental (with a life-cycle approach), Economic, Social (taking into consideration stakeholder engagement and impact on society). The ambition of the project	Stakeholder engagement; Industrial symbiosis mapping;

Project	Project Group	Short Description and Transferable Knowledge	Related Concepts
		is that the model developed can be replicated in other regions and other value chain scenarios. FISSAC aims to demonstrate the effectiveness of the processes, services, and products at different levels.	
FUDIPO https://fudipo.eu/	H2020 SPIRE	The FUDIPO project integrates machine learning functions on a wide scale into several critical process industries, showcasing radical improvements in energy and resource efficiency and increasing the competitiveness of the European industry. Direct output is a set of tools for diagnostics, data reconciliation, and decision support, production planning and process optimisation including model-based control	Machine learning; Process optimisation
HARMONI https://harmony-h2020.eu/	H2020 SPIRE	HARMONI aims at bringing together all the relevant stakeholders of the process industry to jointly identify, analyse and propose solutions to the regulatory bottlenecks and standardisation needs that hamper their innovation processes and the market uptake of their results, necessary to move towards a more sustainable and competitive European process industry. In addition, HARMONI will analyse, compare and propose recommendations to trigger the transferability of technical solutions among and beyond the SPIRE sectors	Stakeholder engagement; Policy recommendations; Value chain uptake
INSPIREWater https://www.spire2030.eu/inspirewater	H2020 SPIRE	INSPIREWATER demonstrates a holistic approach for water management in the process industry using innovative technology solutions from European companies to increase water and resource efficiency in the process industry. This will put Europe as a leader on the world market for segments in industrial water treatment which will create new high-skilled jobs in Europe. INSPIREWATER addresses technical and non technical barriers, as innovation needs both components and demonstrates them in the steel and chemical industry. A flexible system for water management in industries that can be integrated into existing systems is worked out and demonstrated to facilitate the implementation of technical innovations. This will increase process water efficiency as well as resource, water and energy savings in the process industry.	Hollistic water management; Water management policies; Recycling and reuse water technologies

Project	Project Group	Short Description and Transferable Knowledge	Related Concepts
IntelWatt https://www.intelwatt.eu/	H2020 SPIRE	IntelWatt develops innovative, cost-efficient, smart separation technologies applied in energy- and water-intensive industries. The proposed solutions will also target zero liquid discharge while implementing maximum water reuse	Resource recovery; ZLD; Recycling and reuse water technologies
IWAYS https://www.iways.eu/	H2020	IWAYS project aims to introduce several technologies that are focused on environmental challenges while also assisting economic growth and productivity. The project will develop a set of technologies capable of recovering water and energy from exhaust gases in industrial processes. Furthermore, the solutions provided by the project will recover additional materials from flue gas such as valuable acids or particulates, improving the raw material efficiency in production and reducing detrimental emissions to the environment.	Resource recovery; Recycling and reuse water technologies
MONSOON https://www.spire2030.eu/monsoon	H2020 SPIRE	This project aims to provide Process Industries with dependable tools to achieve improvements in the efficient use and re-use of raw resources and energy via a data-driven methodology supporting the exploitation of optimization potentials by applying multi-scale model based predictive controls in production processes.	Process optimisation; Data driven analytics
REFLOW https://reflowproject.eu/	Other	MSCA project dedicated to the recovery of phosphorous from the dairy industry.	Business models; Value chain models; Recovery of nutrients
ReWaCEM https://rewacem.eu/rewacem-resource-recovery-from-industrial-waste-water-by-cutting-edge-membrane-technologies.html	H2020 SPIRE	The ReWaCEM project aims at reducing water use, wastewater production, energy use, valuable metal resource recovery and water footprint in the metal plating, galvanizing and printed circuit board industry. ReWaCem will adopt two cutting-edge membrane technologies suitable for the requirements of closed material cycles approaches and recovery concepts in the metal processing industry.	Resource recovery
SCALER https://www.scalerproject.eu/about-scaler	H2020 SPIRE	SPIRE project looking to assess the potential for industrial symbiosis in Europe and recommend policies. STRANE's startup Seitiss exploits some of the results on resource matching and synergy identification, and methods for developing new business models.	Potential for industrial symbiosis; Industrial synergy identification; Business models;

Project	Project Group	Short Description and Transferable Knowledge	Related Concepts
			IS policy recommendations
SPOTVIEW http://www.spotview.eu/	H2020 SPIRE	The project was to develop and demonstrate innovative, sustainable and efficient processes and technology components, to optimize the use of natural resources, especially water, in three industrial sectors (Dairy, Pulp and Paper and Steel). Technologies were evaluated in terms of environmental impacts and benefits, generated by achieving the SpotView targets (20% to 90% reduction of water usage, wastewater emissions, chemicals and energy use). Economic exploitation of the technologies is pursued through a well-described business case scenario	Process optimisation; Business model; Recycling and reuse water technologies
ULTIMATE https://ultimatewater.eu/the-project/	H2020 SPIRE	ULTIMATE aims to create economic value and increase sustainability by valorising resources within the water cycle. Wastewater is not only a reusable resource but also a carrier for energy and components that can be extracted, treated, stored, and reused. Drawing on "Water Smart Industrial Symbiosis" (WSIS) wastewater recycling is promoted in various industrial settings. Nine large-scale demonstration cases from the four most important industrial sectors in Europe: Agro-food processing, heavy chemical/petrochemical, beverages, biotech industry. It will develop a comprehensive toolbox and include advanced business and financing models	Water-smart industrial symbiosis; Synergy identification; Simulation; Innovative AI for reusing/recycling water
Waste2Fresh https://waste2fresh.eu/	H2020 SPIRE	Waste2Fresh addresses freshwater resource scarcity and water pollution challenges exacerbated by energy-intensive industries which are major users of fresh water and pollute freshwater resources. Breakthrough innovations are needed in energy-intensive industries to recycle water and create closed loops in industrial processes.	Recycling and reuse water technologies
WATER-MINING https://watermining.eu/	H2020	H2020 project aimed at real-world implementation of Water Framework Directive and the Circular Economy through the demonstration of pre-commercial water technology.	Business Models; Process Optimization; Simulation;

Project	Project Group	Short Description and Transferable Knowledge	Related Concepts
			Augmented Reality
ZERO-BRINE https://zerobrine.eu/about-us/	H2020 SPIRE	This project aims to facilitate the implementation of the Circular Economy package by developing the necessary concepts, technological solutions and business models to re-design the value and supply chains of minerals and water while dealing with present organic compounds in a way that allows their subsequent recovery	Business model; Resource recovery; Recycling and reuse water Technologies

Table 4- Projects and knowledge related to AquaSPICE's concepts

5. Review on the Current State of the Art

5.1. Industrial Water Efficiency and Approaches and Practices

The industrial sectors use a considerable amount of water from surface and ground water sources. Accordingly, it is expected that they promote water efficiency practices. Many companies have designed their own water sustainable goals with various water efficiency and conservation programmes. These programmes are typically intended to extend the life of existing raw water supplies and minimise the impacts of water shortages. Below are a few industrial case examples that demonstrate good practices to enhance water efficiency.

5.1.1. L'Oréal's "Waterloop Factory"

L'Oréal has a target to reduce its water consumption by 60% per finished product. To achieve that, L'Oréal has been working on this target from various angles - from optimising consumption and developing projects to treat, recycle and reuse water at its production sites.

Currently, L'Oréal has 4 'waterloop factories' in Burgos (Spain), Settimo (Italy), Vorsino (Russia) and its latest one in Libramont (Belgium). The idea of 'waterloop factory' is to ensure that all the water used to run the factory (for cleaning tanks, producing steam, utilities, etc) originates from water reclaimed on site[82].

L'Oréal monitors and maps their plants' water consumption via the "Water scan tool," a standard tool for analysis and exhaustive mapping of water consumption. This tool helps categorise the different uses of water (such as washing, cooling and sanitation) and identify consumption for each of these [83].

5.1.2. Formosa Taffeta's Right First Time Dyeing Technique to use AI in Reducing Water Consumptions

Formosa Taffeta is a textile production and sale company, and one of the largest water consumers among the process industries. Formosa Taffeta is aiming to reduce water consumption with the implementation of the "Right First Time" fabric dyeing technique. This dyeing technique uses AI to forecast the most efficient dyeing "curve" and optimises the process. As a result, Formosa Taffeta is able to save their water, energy and raw material costs by NT$ 22.65 million (approximately € 0.7 million) per year and reduces 2,630 ton CO_2 of carbon emission per year [84].

5.1.3. Wastewater Reuse in Arla Dairy Plant [85], [86]

Danish Arla dairy Rødkærsbro is a dairy plant that produces mozzarella cheese. The cheese making process produces a lot of water since milk is the raw product containing approximately 85% of water [87]. On average, Rødkærsbro dairy produces 1,250 m^3 of nitrogenous rich wastewater - the 'cow water' daily. The amount of wastewater not only increases the environmental load but is also costly to send the water to be treated in the centralised wastewater treatment plant as the tax is proportional to the amount of organic material in the wastewater. As a solution, Arla teamed up with the Danish pump manufacturer Grundfos to build a decentralised unit, the 'BioBooster' unit that treats the wastewater from the cheese plant. The process is coupled with a routine involving online monitoring and a dissolved air flotation pre-treatment step. The result is satisfactory and the treated water is partially being reused in the plant, reducing groundwater abstraction by 750m^3 daily [85]. Furthermore, the treated water is of higher quality, with minimised nitrogen and phosphorus, can be discharged into the local river and satisfies Denmark's regulatory requirements.

In England, Arla's Aylesbury plant processes up to one billion litres of milk a year from British farms. The company works with Veolia to install an Anaerobic Membrane Bio-Reactor as an on-site wastewater treatment solution, effluent from the treatment can be reused or discharged directly to the sewer. Arla can remove the COD load in the wastewater by an average of 99.4% and producing treated effluent of exceptional quality to be reused in the industry, thus reducing freshwater abstraction by combining the reuse of treated wastewater with a rainwater harvesting system.

5.1.4. Food Processing Industry: Frito-Lay Process Water Recovery Treatment Plant

Frito-Lay's Casa Grande food manufacturing plant in the U.S. state of Arizona has an ambitious goal of running the entire plant on renewable energy and recycled water while producing less than 1% landfill waste.

The installation of a new process water recovery treatment plant and recycling facility enables the plant to reclaim and reuse more than 75% of the plants' process water for cleaning and production needs, resulting in a huge reduction in wastewater discharge. The recovery system utilises advanced membrane technology to enable the quality of reclaimed water to meet U.S. EPA drinking water standards [88].

5.1.5. HEINEKEN's Every Drop 2030 Strategy

The multinational brewing company, HEINEKEN is planning to develop a more holistic approach to support the health of watersheds, especially in water stressed areas by adopting three key principles, namely Water Stewardship (restore watersheds to absorb more water); Water Circularity (treat wastewater and reusing water); and Water Efficiency (using as little water as possible). HEINEKEN has started to look into the water-related risks in 2010 to assess water quantity and quality, local water regulations and stakeholder interests around the breweries. Through the Every Drop Strategy, HEINEKEN has successfully achieved a 33% decrease in water consumption in the breweries since 2008, an economic saving of €15m through water efficiency since 2009 and 97% of the wastewater produced from the breweries are treated before discharge [89].

5.1.6. Nissan Motor Water Resource Management

Nissan Motor is a multinational automobile manufacturer, and the company has set up the Nissan Green Programme 2022 targeted to reduce water intake at global production sites by 21% by 2022 and to approach zero liquid discharge. The progress in the past few years can be seen in Figure 10. In Nissan India production site, the company has set up different innovations such as rainwater harvesting and wastewater recycling to allow the site to be independent of external water sources for 130 days. Another example of Nissan's water efficiency practice is that in their Japan production site, the company has deployed water quality sensors at the wastewater treatment facilities and automated the process of suspending water discharge if any water quality issue arises. The company also aims to achieve zero water discharge by using a reverse osmosis system to process wastewater to be recycled on some sites [84], [90].

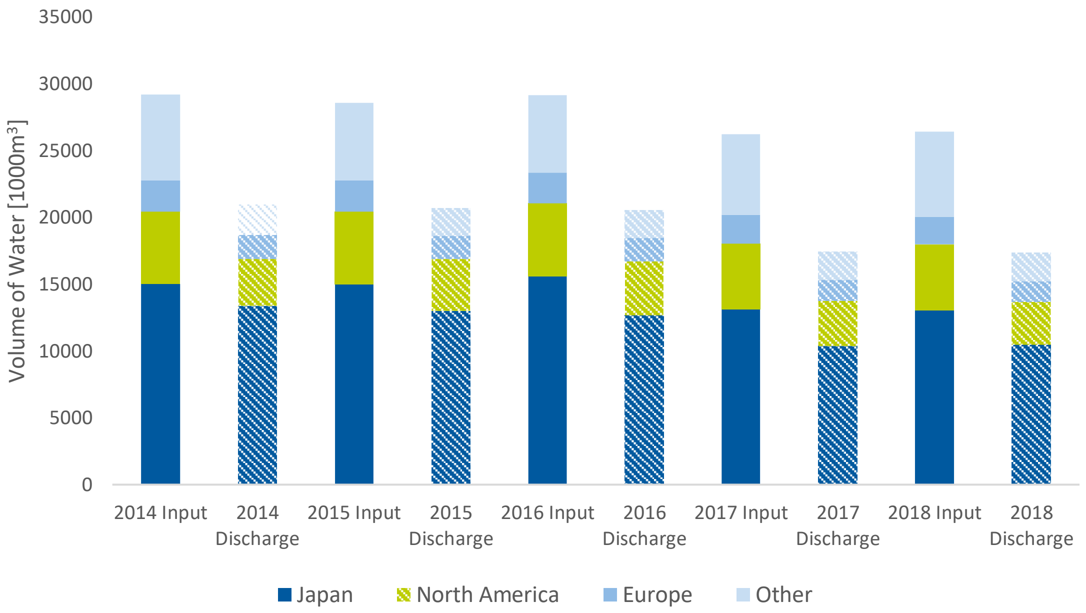

Figure 10- The volume of water abstraction and treated wastewater discharge in Nissan Motor globally.

5.2. Process Technologies for Circular Water Use in the Process Industry

As discussed in Section 3.3.8, the process technology to advance water circularity is not a straightforward approach. There is no one technology fits for all purpose of water reuse. Instead, different technologies and technology treatment train combinations need to be considered, depending on various factors such as required effluent qualities (and the level of compliance needed), influent characteristics, local constraints and financial possibilities.

(Inter-) Process-integrated solutions including non-traditional water sources such as rainwater are to be looked for to foster the transition from a linear to a circular water economy. Oftentimes, former water treatment facilities exist, which require upgrading/retrofitting to approach an advanced process-circular-digital integrated solution.

One of the indicators to determine process technologies (and combinations thereof) is the technology readiness level (TRL). While a TRL of 1 (lowest level) implies that the basic principles of the specific technology have been observed, a TRL of 9 (highest level) implies that the actual system has been proven in an operational environment [91]. Thus, usage of technologies having lower TRLs usually implies higher risks of failure to the operator.

Possible treated industrial water end-use areas (meaning different water qualities requirements) include:

- cooling,
- resource extraction (including mining, oil and gas exploration),
- irrigation and
- cleaning.

While The International Organisation for Standardisation (ISO) water quality specifications for cooling focus on minimising the negative impacts on the cooling system (metal corrosion, biofouling, disinfection by-products, biomass growth, scaling, etc) [92], water quality specifications for agricultural or urban irrigation purposes focus on safeguarding public health as well as soils/groundwater, indicating microbiological quality guidelines, trace element limitations, as well as further quality parameters (e.g. salinity, ion concentrations) [93], [94]. Thus, different goals for water reuse imply different process technologies and treatment trains.

Some of the main treatment options applied in water and wastewater treatment can be summarised below and more information is found in Appendix II: Overview of Process Technology in Water and Wastewater Treatments.

- Mechanical processes
    - Sedimentation
    - Centrifugation
    - Flotation
- Thermal processes
    - Evaporation
    - Distillation
    - Rectification
    - Stripping
    - Extraction
- Biological processes
    - Conventional Activated Sludge
    - Membrane Bioreactor
    - Membrane Aerated Biofilm Reactor
    - Moving Bed Bioreactor
    - Granular Sludge System
    - Trickling Filter
    - Constructed Wetlands
    - Biological Activated Carbon
- Chemical Processes
    - Neutralisation
    - Coagulation
    - Flocculation
    - Softening
    - Oxidation
    - Advanced Oxidation Processes
    - Disinfection
    - Photolysis
- Filtration Processes
    - Membrane Filtration
        - Microfiltration
        - Ultrafiltration
        - Nanofiltration
        - Reverse Osmosis
        - Ion Exchange Membrane
        - Membrane Distillation
    - Deep Bed Filtration
        - Slow Sand Filtration
        - Rapid Sand Filtration
        - Multimedia Filtration

5.3. Digital Enablers for Water Reuse under the Circular Economy Paradigms

Human activities have become the main driver of global change such as climate change, environmental pollution and increasing scarcity of resources. These activities have deteriorated the ecosystems and also contributed to climate change impacts. To reduce this contribution and fight against climate change, industries are aligning themselves to increase the reusability of resources in their process as a strategy to be more sustainable. With this growing realisation, the role of digitalisation is a key factor to better understand symbiotic relationships between processes and industries, simultaneously exploring and analysing data to optimise the process towards efficiency and zero waste.

Under these objectives, industries are putting efforts under three main pillars: (a) cyber-physical systems (CPS); (b) interoperability and data sharing; and (c) AI-driven algorithms for optimising processes and enabling resource reuse.

Figure 11 below illustrates the smart architectures and the digitalisation landscape where these three main pillars operate.

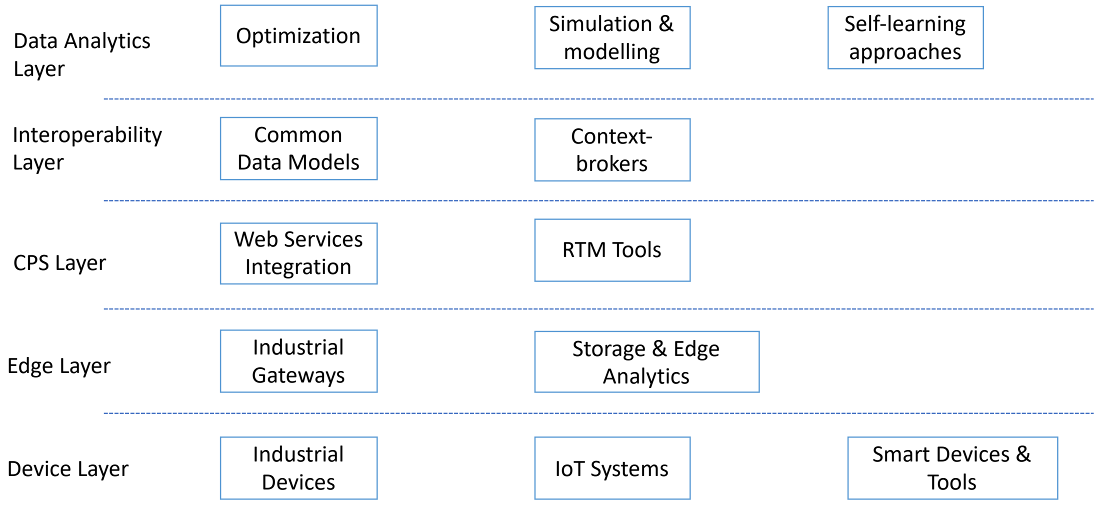

Figure 11- Smart architectures and digitalisation landscape.

The **CPS** concept has been evolving since its first demonstration in 2006 and creates unprecedented innovation opportunities [95]. The CPS begins with a focus on parameters monitoring and processes/machines control [96]. Currently, these systems are key enablers for process monitoring and control autonomously, being one of the main drivers for Industry 4.0. Thanks to the sensor and digital revolutions, the CPS is able to utilise cost-efficient sensor technologies, also known as the Internet of Things (IoT). The IoT systems allow the monitoring of certain parameters even in harsh conditions such as the industrial environments. Nowadays, IoT systems contain sufficient computational technology to permit them to analyse data in-situ thus determine critical events. This aspect is a huge advancement in terms of enabling decisions at the edge up to a certain level. Despite these promising characteristics, the CPS still has challenges to face on. In that sense, the CPS needs to deal with the process complexity and the process of monitoring designs require experts and process modellers to work together to elaborate the efficiency and suitable solutions [96]. Indeed, it is required to balance and manage the complexity and subsequent risks of implementing and adopting the CPS in terms of environmentally sustainable critical events and circular economy pathfinders. Complementary, this kind of digital asset requires to be interconnected in terms of data models to tackle collaborative decisions. Under these aspects, future trends will be under federated learning approaches and also, computing continuum approaches [97].

Complementing the CPS architectures at the physical level, digital architectures also cover **interoperability and data sharing digital tools** as a key enabler to facilitate data analytics and also exploration and navigation through the information using common and agreed models. The initial concept was named “Semantic Sensor Web” in 2011 [98]. This initial concept describes the needed mechanism to share data using common data models based on semantic modelling (ontologies). Since then, this concept has been evolving drastically passing from custom semantic architectures [98] to standardised based ones. In relation to the standard architectures, OneM2M has been one of the models to represent industrial information [99]. Similarly, in water, the Open Geospatial Consortium (OGC) uses a standardised architecture called “Observation & Measurement” [100]. Considering these architectures, the main gaps were focused on close-based standards that impede a wide usage of the information modelling. Also, there are sectorial specific architectures that are enablers for the fragmentation of different infrastructures as water, energy and industrial. Based on this, nowadays challenges are on cross-relating the different linked infrastructures (industry-water, industry-energy, energy-water) to enable newer decisional-making strategies and methodologies coming from cascading decisions from other sectors. In this regard, the European Commission is promoting FIWARE [101] as a reference architecture to connect different devices and platforms at a high level scale. Under this high level architecture, efforts on standardising the information are under the so-called “Context-Broker” [102] that enables the connections of different IoT devices and the subsequent information under common data models. At the international level, the W3C standard called Web of Things [103] serves similar purposes. Despite the huge advancements, there are gaps in linking the information using open models. Another relevant challenge is to expand their use and continuing with the elaboration and updating of the data models to feed into the high-level architecture. Finally, there is also an important need for the elaboration of “plugins” and “Agents” to transform the specific data models (COAP, ModBus, etc) to the common data model itself. Therefore, a strong commitment to a community is needed.

Considering the third mentioned pillar (**data analytics and artificial intelligence**), the more common approach is focusing on the use of simulations over the processes (e.g. using Six Sigma) to detect weak industrial process practices and try to make them more efficient [104]. Moreover, this simulation was also combined with process modelling to introduce newer variables and flows (e.g. water, energy, etc). Thus, this combination of modelling and simulation tools aid the decision making process from the perspectives of digitalisation of physical industrial flows and processes [105]. However, these models are difficult to maintain and update due to their complexity. The emergence of artificial intelligence and concrete data analytics technologies have enabled industries to use data to optimise processes, such as the use of artificial neural networks [106], support vector machines [80], artificial bee colonies [107], among others. Despite these efforts, one of the main gaps of these algorithms is the required data to make them operational is not always sufficient. Hence, the current trend is to make the systems more autonomous, trustworthy and self-learning as newer innovations. Thus, the emerging trends of the application of the hybrid simulation and optimisation [108] and the reinforcement learning approaches can be observed [109]. All of these activities are part of the paradigm shift to the application of cognitive architectures.

6. Conclusions

The rapid development of industrial activities globally has increased the demand for the world's limited supply of resources 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 innovations approach of advancing the industrial circular water use remains unexploited. The drivers to achieve a better circularity in the European process industry varies under the influence of political, environmental and economic pressures or benefits. 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 implementation support measures on a harmonised European level. On the other hand, the increasing longing to achieve a more efficient industrial water management 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 in the aspects of more process industries focused guidelines.

This report summarises the drivers, opportunities, gaps and barriers to enhance water use in the process industry. It also provides some potential recommendations and actions from several of AquaSPICE’s tasks and deliverables to attempt to close these gaps, from the vantage of technical, legislation, social and economic aspects. Accordingly, it also provides support and information for developing a water efficiency enhancement framework for the process industry.

In conclusion, even though challenging, there is a pressing need to address the gaps and barriers identified in this review. Hence, the development of a holistic methodological and technical water efficiency enhancement framework that encompasses all aspects of industrial water use is beneficial to be used as guides and pointers to materialise circular water use in the European process industries.

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8. Appendix I: Different Cost Models Used in Literature for Cost Estimations

Cost Models	Type	Descriptions
WT Cost II [110]	Parametric	A computer cost estimating program to evaluate any treatment system using a standard desalination cost format, including membrane desalination (reverse osmosis and nanofiltration), thermal evaporative desalination plants using technologies of multistage flash distillation, multi-effect distillation and vapour compression (mechanical and thermal), ion exchange and electrodialysis.
Desalination Economic Evaluation Program (DEEP) [111]	Parametric	A spreadsheet tool used to conduct preliminary economic evaluations to compare performance and cost estimates of various desalination. Other uses include power configurations estimates of technical performance and costs for various desalination technology configurations.
Parametric Design & Cost Estimating System (CPES) [112]	Parametric	Cost estimations and conceptual-level designs for municipal and industrial water and wastewater projects. Usually applied for sustainable and economical decision-making in an early stage of a project. The model provides facility design, construction cost estimating, and lifecycle cost estimating.
Carollo Cost Estimating System (CCES) [113]	Parametric	A construction estimation software with access to the construction material information and conduct a cost estimation to be incurred in a project based on material prices, and locations.
Leitner database [114]	Empirical	A cost database based on 180 desalination plants in the United States, Canada, and the Virgin Islands.
GWI Desal Data Cost Estimator [115], [116]	Empirical	A cost estimator based on the database of desalination water treatment plant cost to generate capital and operating costs for seawater reverse osmosis, multi-effect distillation and multistage flash distillation. Capital costs are estimated through the input of quantitative and qualitative design parameters, including treatment technology, capacity, salinity, feed water temperature, location, and complexity of pre-treatment, intake, and permit.
Cost Estimating Manual for Water Treatment Facilities [117]	Empirical	A book that provides construction and operations and maintenance costs estimations for the preliminary design of WTPs. Equations and cost curves are provided for operations and maintenance costs can be applied for 14 different types of unit processes.
Unified Costing Model (UCM)	Empirical	Cost estimations used in the Regional Water Planning Groups in Texas. The model contains modules to estimate the costs of pipelines, well fields, embankments, land acquisition, and water treatment (based on capacity and types of treatment). This tool

Cost Models	Type	Descriptions
		was developed for the preparation of regional water planning level cost estimations and not to be used in place of professional engineering design.
Wittholz Model [114]	Empirical	A power-law model cost correlation derived from existing cost data from 331 desalination plants. Cost data collected to derive the model includes capital cost, fixed cost, operating cost per year per cubic meter and unit cost. The capital cost included the plant and land costs, civil works, and amortisation.

9. Appendix II: Overview of Process Technology in Water and Wastewater Treatments

Treatment Options and Examples	Examples, Comments and Applications
Mechanical processes - Sedimentation - Centrifugation - Flotation	Mechanical processes are commonly used in the primary treatment of wastewater. Centrifugation involves investment and operational costs of the centrifuge itself, it is more expensive than a simple clarification basin. However, especially for processes like sludge dewatering, centrifugation is often used due to otherwise low sludge dewaterability and as an intensified process. In flotation (often dissolved air flotation (DAF)), the separation of solid/liquid is achieved by the solids attaching to fine gas bubbles, usually air (nitrogen or fuel gas are commonly used in the oil industry). The buoyant particles accumulate at the water surface and are collected with skimmers and thus removed. Depending on the particle characteristics to be removed, one or the other process is favourable. In comparison to sedimentation, flotation requires less volume, the abatement efficiency is unaffected by changes in the flow rate and it achieves higher dry matter content in the sludge [91].
Thermal processes - Evaporation - Distillation - Rectification - Stripping - Extraction	Evaporation/Distillation processes as applied often for seawater desalination purposes (e.g., Multi-Stage Flash (MSF) and Multi-Effect Distillation (MED) in cases where e.g., thermal energy is cheap and/or salinity of feed water high (> 100 g/L [118]) instead of reverse osmosis (RO) processes. Other application examples are the removal of certain organic compounds from wastewaters such as ethylene glycol, acetic acid, pyridine (with Distillation, Rectification), toluene, aniline (with stripping), and phenols, oil removal (with extraction) [119].
Biological processes - Conventional Activated Sludge (CAS) system - Membrane Bioreactor (MBR)	Biological treatment processes involve the conversion of organic matter and/or other constituents like nutrients (Nitrogen and Phosphorous) to gases and cell tissue by a large mass of microorganisms using a limited quantity of chemicals. The removal rate is highly dependent on the biodegradability of organic substances. It can be estimated by its BOD/COD ratio

Treatment Options and Examples	Examples, Comments and Applications
• Membrane Aerated Biofilm Reactor (MABR) • Moving Bed Bioreactor (MBBR) • Granular Sludge System • Anaerobic Digestion • Trickling filter • Constructed wetlands • Biological Activated Carbon (BAC)	(before treatment): relatively non-degradable wastewater if below 0.2, moderately to highly degradable when 0.2-0.4 and highly degradable if greater than 0.4. There are three types of metabolic processes [91]: • aerobic processes: – the organic compounds are converted (mineralised) into carbon dioxide, water or other metabolites and biomass (i.e. the activated sludge) in the presence of oxygen • anoxic processes, using the biological reduction of oxygen donors; • anaerobic processes- converts the organic content of wastewater, with the help of microorganisms and without air supply, to a variety of products such as methane (70%), carbon dioxide (30%), sulfide, etc without an oxygen supply. The advantage of anaerobic pre-treatment is the low amount of excess activated sludge produced during the process, and considerably less energy consumption because there is no energy need for air or oxygen supply to the reactor, but only for efficient stirring [91]. On the other hand, nutrients like ammonia and phosphate are not removed in the process. Conventional systems work with suspended biomass (sludge) that is sent to a settling tank and then recycled to the biological tank. It is a large process footprint where removal efficiency is strongly influenced by the sedimentation process. The membrane bioreactor consists of membrane modules (either micro or ultrafiltration) immerged into an aerated activated sludge tank. The effluent is filtered through the hollow fibre membrane, and the biomass remains in the tank reducing space requirements. Pre-treatment steps like fine screening are necessary to prevent clogging. In a trickling filter, microorganisms are attached to a highly permeable medium (normally rock or various types of plastic) through which the wastewater is trickled or percolated; suspended solids are retained in the filter, from where they are back-washed regularly. This technology has been developed as a compact (high turnover rate per volume and omission of a secondary clarifier) and odourless alternative to the conventional activated sludge process. Similarly, a biological

Treatment Options and Examples	Examples, Comments and Applications
	activated carbon reactor is an emerging technology that combines the adsorption performance of granular activated carbon (GAC) with the biological activity of microorganisms that grow on the activated carbon. Biological processes also include nature-based solutions. Constructed wetlands, for instance, are engineered systems (typically long, narrow trenches or channels) that utilize the natural processes involving wetland vegetation, soils and microorganisms including sedimentation, chemical precipitation and adsorption, and biodegradation by microorganisms. The type of wetland can be distinguished according to the presence/absence of free water surface, use of rooted emergent aquatic plants (or free-floating plants), and direction of flow. Even if they are based on a natural and sustainable approach, also acting as useful wildlife habitats, they require a high footprint and the operational control over the process is quite limited.
Chemical Processes • Neutralisation • Coagulation • Flocculation • Softening • Oxidation • Advanced Oxidation Processes (AOPs) • Disinfection • Photolysis	Chemical Unit processes are used commonly in conjunction with the physical/ mechanical unit processes to meet specific treatment objectives. Coagulation and flocculation are useful to prevent fouling on membranes processes by producing more permeable deposits. Coagulation is the process whereby a given system may be transformed from a stable to an unstable state: for example, in the case of dispersing suspensions or solutions, visible floc or precipitate formation occurs; in the case of highly concentrated suspensions, dewatering of the sludge mass occurs, and so on. Meanwhile, flocculation is the process whereby the manifestation of destabilization is realized by changing the physical characteristics of the flocs formed (for example, their strength, size, and density) to accelerate their growth. After coagulation and flocculation, the destabilized and flocculated stream is passed to a solid-liquid separation stage where flocs are either separated by gravity or are filtered from the liquid. (Coagulation and Flocculation in Water and Wastewater Treatment, 2nd Edition John Bratby). In wastewater treatment facilities, metals are removed by precipitation as metal hydroxides. Lime or caustic is added to reach the pH of minimum solubility that varies with the metal in question, the operating temperature, the constituent of wastewater and concentration of organic matter. Because of the many uncertainties, laboratory bench scale or pilot plant testing should be conducted to evaluate the best dosage and operating conditions.

Treatment Options and Examples	Examples, Comments and Applications
	Conventional chemical oxidation processes in wastewater treatment generally involve the use of different oxidizing agents (chlorine, ozone, chlorine dioxide, permanganate, and hydrogen peroxide) to change the chemical composition of a compound or a group of compounds. The rate of oxidation typically follows the trend given below: $HO\cdot > O_3 > H_2O_2 > HOCl > ClO_2 > MnO_4^- > O_2 > OCl^-$ Main applications are for odour control, hydrogen sulfide control, colour removal, iron and manganese removal, disinfection, control of biofilm growth and biofouling in treatment processes and distribution system components, and oxidation of selected trace organic constituents. In addition, chemical oxidation is now commonly used to improve the treatability of non-biodegradable (refractory) organic compounds, eliminate the inhibitory effects of certain organic and inorganic compounds to microbial growth, and reduce or eliminate the toxicity of certain organic and inorganic compounds to microbial growth and aquatic flora. Aside from the expense of chemical additives, the primary concern with any chemical oxidation process is the potential for the formation of toxic by-products due to incomplete oxidation. Inorganic and organic chemicals are also broken down by photons (photolysis) emitted by the light in the ultraviolet (UV) range (200 to 400 nm). The reactors typically consist of a stainless-steel column or pipe containing UV lamps. Fouling that may occur on the outside of the UV lamp protective quartz sleeve may be managed using an automatic cleaning system. UV lamps (low-pressure low-intensity, low-pressure high-intensity, or medium-pressure high-intensity lamps) are chosen according to the constituent to be removed as well as the water matrix and site-specific conditions. Advanced oxidation processes can be used to destroy trace constituents that cannot be oxidized completely by conventional oxidants. They generate elevated concentrations of hydroxyl radical, as strong oxidant, that react rapidly with nearly all electron-rich organic compounds, capable of the complete oxidation of most organic compounds into carbon dioxide, water, and mineral acids. In water reclamation, AOPs are usually applied to low COD wastewaters (typically the following treatment by reverse osmosis) because of the cost of ozone and/or H2O2 required to generate the hydroxyl radicals. The commercially available AOPs for water reclamation are ozone/UV, ozone/hydrogen peroxide, and hydrogen peroxide/UV. It should be noted that following oxidation, constituents that were previously resistant to degradation may be transformed into biodegradable compounds that will require further biological treatment.

Treatment Options and Examples	Examples, Comments and Applications
Filtration processes • Membrane filtration ○ Microfiltration (MF) ○ Ultrafiltration (UF) ○ Nanofiltration (NF) ○ Reverse Osmosis (RO) ○ Ion Exchange Membrane (IEM) ○ Membrane Distillation (MD) • Deep bed filtration ○ Slow Sand Filtration ○ Rapid Sand Filtration ○ Multimedia Filtration (MMF)	Different types of membranes are used for wastewater treatment and water reuse projects: Microfiltration (MF) membranes (pore sizes in the range 0.1 to 5 μm), Ultrafiltration (UF) membranes (5 to 200 nm), Nanofiltration (NF) membranes (pore sizes down to 1.5 nm or lower), Reverse Osmosis (RO) membranes (no pores), and Anion/Proton Exchange Membranes (AEM/PEM). While MF and UF are the “pore-type” membrane processes, which operate like sieves retaining suspended matter, NF and RO are “solution-diffusion” membranes, retaining salts and dissolved substances. AEM/PEM are used within the Electrodialysis (ED) and Electrodialysis Reversal (EDR) process, tailored to retain only anions or cations, respectively [91], [118]. In membrane distillation (MD), yet an emerging technology (TRL 3 [120], thermally driven vapour molecules are transported through a porous hydrophobic membrane. Deep bed filtration processes, such as slow and rapid sand filtration (SSF/RSF), multimedia filtration (MMF) as well as biologically active carbon filtration (BAC) or granular activated carbon filtration (GAC) have been extensively applied either as pre-treatment processes or polishing steps across industries in combination with other processes (e.g., ozonation and coagulation/flocculation). Another process to remove ions from a specific stream is the Ion Exchange (IE). In this unit process in which ions of a given species are displaced from an insoluble exchange material by ions of a different species in solution. The most widespread use is in softening process, where sodium ions from a cationic exchange resin replace the calcium and magnesium ions in the treated water, thus reducing the hardness. Anionic exchange resins are also deployed in the removal of nitrogen, heavy metals, and total dissolved solids.

10. Appendix III: Relevant H2020 Projects

Acronym	Programme	Title	Project Link
AccelWater	H2020-EU.2.1.5.3.	Accelerating Water Circularity in Food and Beverage Industrial Areas around Europe	
ALGAMATER	H2020-EU.3.5.;H2020-EU.2.3.1.	Using microalgae bioreactor technology to deliver the world's most cost-effective, energy-efficient and adaptable system for the treatment of toxic industrial and landfill wastewater	http://en.bluemater.com/bm-wwtp/
algaPLUS	H2020-EU.3.5.;H2020-EU.2.3.1.	Upscale and optimisation of an olive wastewater treatment photobioreactor (PBR) coupled to algae biomass valorisation as biofertilizer and treated water reuse	http://www.biot.es/index.php/en/
AMR-G	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Smart your Water Meter	https://www.smartamr.com/
Anaergy	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Ultra-efficient Multi-phase Sequential Waste Water Treatment Technology	http://ingeobras.com/proyecto-anaergy-en-el-programa-horizon-2020-fase-1/
ANAERGY	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Advanced Multistage Sequential Wastewater Treatment Technology	http://ingeobras.com/en/agri-food-water-treatment-anaergy/
ANSWER	H2020-EU.1.3.1.	ANtibioticS and mobile resistance elements in WastEwater Reuse applications: risks and innovative solutions	http://answer-itn.eu/
AQUA PUR TM	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Development and market penetration of an innovative water purification technology for industrial applications	http://www.bioazul.com
AquaGen	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Water quality biomonitoring combining AI and environmental genomics	https://id-gene.com/aquagen-project/

Acronym	Programme	Title	Project Link
AQUA-REUSE	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	ReAl-time online QUality Assurance for REUSE of water	http://aqua-q.se/
AQUASENSE	H2020-EU.1.3.1.	Innovative Network for Training in wAter and Food QUality monitoring using Autonomous SENSors and IntelligEnt Data Gathering and Analysis	
BioFlot	H2020-EU.1.3.2.	Critical metal recovery from industrial wastewater by bioflotation using surface active siderophores	
BioMicroGels	H2020-EU.2.1.5.;H2020-EU.2.1.3.;H2020-EU.2.3.1.;H2020-EU.2.1.2.	Innovative environmentally-benign wastewater treatment reagents offering a step change in efficiency in the cleaning of water from oils and metal ions and in liquidation of emergency oil spills	http://biomicrogel.com/en/
BRINE MINING	H2020-EU.2.3.2.2.	Applying circular economy solutions in industrial wastewater management: request of SME Associate to develop the necessary energy simulation tools for recovery of waste heat from industrial operations	http://sealeau.com/index.php/projects
CellCount	H2020-EU.3.2.4.;H2020-EU.3.2.1.;H2020-EU.2.3.1.;H2020-EU.3.2.2.	CellCount, a revolutionary technology platform to solve current problems with microbiological contamination in water and food industries.	https://www.rqmicro.ch
CENSE	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Enabling the continuous monitoring of drinking water with an all-in-one sensor	
CGM	H2020-EU.2.1.5.;H2020-EU.2.1.3.;H2020-EU.2.3.1.;H2020-EU.2.1.2.	A next generation nano media tailored to capture and recycle hazardous micropollutants in contaminated industrial wastewater.	http://www.customem.com
CleanHydro	H2020-EU.3.5.;H2020-EU.2.3.1.	SUSTAINABLE WATER TREATMENT FOR EUROPEAN INDUSTRY - ACHIEVING REGULATORY COMPLIANCE AND ENVIRONMENTAL PROTECTION	http://www.swehydro.se/

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CleanOil	H2020-EU.3.5.;H2020-EU.2.3.1.	Global business challenge: Breaking the oil gas water dependency with a cost-effective no-waste nanomembrane technology for water reuse	http://www.liquid-cleanoil.com/
ColiSense Online	H2020-EU.3.5.;H2020-EU.2.3.1.	Online and automated E. coli monitoring for 100% safe drinking water	https://www.bnovate.com/
CPB 4.0	H2020-EU.3.5.;H2020-EU.2.3.1.	Worldwide unique, resource-conserving and energy-efficient treatment of industrial wastewater polluted by oils and heavy metals for implementing the EU Water Framework Directive in a company	http://www.oko-tech.de/en/news/article/sme-instrument-of-the-eu-innovation-programme-horizon-2020-we-are-part-of-it.html
DATA4WATER	H2020-EU.4.b.	Excellence in Smart Data and Services for Supporting Water Management	https://d4w-twinn.pub.ro
DRYLAP	H2020-EU.3.5.;H2020-EU.2.3.1.	DRY LAPping machine for water saving finishing processes in ceramic sector	http://www.bmr.it/
ECWRTI	H2020-EU.3.5.4.	ECOLORO: Reuse of Waste Water from the Textile Industry	http://ecwrti.eu/
ELECTRAMMOX	H2020-EU.1.3.2.	Bioelectrochemical anaerobic oxidation of ammonia for sustainable N removal from wastewater	
E-motion	H2020-EU.1.1.	Electro-motion for the sustainable recovery of high-value nutrients from wastewater	http://www.louisdesmet.nl
FOODWATER H2020	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Water treatment and reuse technology based on constant water quality monitoring thanks to multi-censoring and AI-Deep Learning software for the Food Industry	http://www.vam-watertech.com/blog/vam-watertech-in-project-foodwaterh2020/
FREEWAT	H2020-EU.3.5.4.	FREE and open source software tools for WATer resource management	http://www.freewat.eu

Acronym	Programme	Title	Project Link
GaLlophore	H2020-EU.1.3.2.	Selective recovery of gallium from wastewaters of GaAs fabrication industry using siderophore based bisorptive biocomposites	https://www.hzdr.de/db/Cms
GENAQ	H2020-EU.3.5.;H2020-EU.2.3.1.	Replicating the Natural Rain Process for a Sustainable Distributed Water Production: More Water with Less Consumed Energy	http://www.genaq.com/home/projects/
GReen Desalination	H2020-EU.3.5.;H2020-EU.2.3.1.	GReen Desalination: A closed-loop technology for full recovery of water and raw materials from the wastewater effluent	http://greendesalination.eu/
H2COLOR-AUX	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	An innovative polymer particle used for textile dying which massively reduces water and energy consumption	https://www.ecofoot.pt/en/
INCOVER	H2020-EU.3.5.4.	Innovative Eco-Technologies for Resource Recovery from Wastewater	http://incover-project.eu/
INNOVCITIES	H2020-EU.1.3.2.	Institutional Innovation for Adapting to Climate Change in Water Governance within Cities	http://www.innovcities.net
INSPIREWater	H2020-EU.2.1.5.3.	Innovative Solutions in the Process Industry for next generation Resource Efficient Water management	https://www.spire2030.eu/inspirewater
INTEGROIL	H2020-EU.3.5.4.	Demonstration of a Decision Support System for a Novel Integrated Solution aimed at Water Reuse in the Oil & Gas Industry	http://integroil.eu/
intelWATT	H2020-EU.2.1.5.3.	intelligent Water Treatment Technologies for water preservation combined with simultaneous energy production and material recovery in energy intensive industries	
IoT4Win	H2020-EU.1.3.1.	Internet of Thing for Smart Water Innovative Networks	http://iot4win-itn.eu
I-SOFT	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Intelligent Electrochemical Cooling Water Softening System	http://www.uetwater.com/

Acronym	Programme	Title	Project Link
iWAYS	H2020-EU.2.1.5.3.	Innovative WAter recoverY Solutions through recycling of heat, materials and water across multiple sectors	
MAYIM	H2020-EU.2.3.1.;H2020-EU.2.1.2.	Integrated method for treating a wide range of industrial waste waters based on magnetic settling and catalytic oxidation	
MEMBio	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Application of Microbial Fuel Cells for waste water treatment	http://www.aeneam.com/ABOUT-NEAM/
MICROWATER	H2020-EU.1.3.2.	Anaerobic methane oxidation processes in wastewater management, as sustainable applications against climate change	
M-NBS	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Smart, flexible, decentralized water treatment	http://www.ayala-aqua.com/
Multi-AD Feasibility	H2020-EU.3.5.;H2020-EU.2.3.1.	High performance MULTIphase Anaerobic Digester for agroindustrial wastewater treatment	http://www.aemaservicios.com/en
NEWAVE	H2020-EU.1.3.1.	Next Water Governance	
NextGen	H2020-EU.3.5.2.3.;H2020-EU.3.5.4.;H2020-EU.3.5.2.2.	Towards a next generation of water systems and services for the circular economy.	https://nextgenwater.eu/
NMRT	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Using Nano-Magnetic Resonance to deliver the world's most cost-efficient system for the treatment of toxic industrial and landfill wastewater	http://www.funcionalst.pt/
NOWELTIES	H2020-EU.1.3.1.	Joint PhD Laboratory for New Materials and Inventive Water Treatment Technologies. Harnessing resources effectively through innovation	
NUCLEARWATERS	H2020-EU.1.1.	Putting Water at the Centre of Nuclear Energy History	
OPTAINER	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	An unprecedented water-recycling system for washing, rinsing and drying of thermal insulated containers within the Food Industry	

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PANI WATER	H2020-EU.3.5.4.;H2020-EU.3.5.2.2.	Photo-irradiation and Adsorption based Novel Innovations for Water-treatment	http://www.paniwater.eu
PAVITR	H2020-EU.3.5.4.;H2020-EU.3.5.2.2.	Potential and Validation of Sustainable Natural & Advance Technologies for Water & Wastewater Treatment, Monitoring and Safe Water Reuse in India	http://www.pavitr.net
PAVITRA GANGA	H2020-EU.3.5.4.;H2020-EU.3.5.2.2.	Unlocking wastewater treatment, water re-use and resource recovery opportunities for urban and peri-urban areas in India	https://pavitra-ganga.eu/en
POWER	H2020-EU.2.1.1.	Political and sOcial awareness on Water EnviRonmental challenges	http://www.power-h2020.eu
PreSTO	H2020-EU.1.3.2.	Pilot scale hybrid Photocatalytic Processes for the simultaneous removal of Pathogens and Pharmaceuticals from wastewaters	
ProbSenS	H2020-EU.1.3.2.	Probabilistic neuromorphic architecture for real-time Sensor fusion applied to Smart, water quality monitoring systems	http://sensors.ini.uzh.ch/home.html
Project O	H2020-EU.3.5.2.3.;H2020-EU.3.5.4.;H2020-EU.3.5.2.2.	Demonstration of planning and technology tools for a circular, integrated and symbiotic use of water	http://eu-project-o.eu
ProTreaT	H2020-EU.3.5.;H2020-EU.2.3.1.	FEASIBILITY ASSESSMENT OF THE GREEN ProTreaT TECHNOLOGY FOR PROTEIN-BASED, NATURAL REMOVAL OF HEAVY METALS FROM WATER AND WASTEWATER	
PureWater	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Feasibility study for industrial scale-up of the novel high-efficiency biocompatible and easy-to-operate water treatment membrane.	http://www.bluact.com
RAINOLVE	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	Accurate irrigation controller with multi-sensoring and interactive cloud-based platform to evaluate real plant needs and save up to 80% of water	http://www.rainolve.it
RECOVERY	H2020-EU.1.3.2.	Water Recovery from Industrial Gas Streams at Moderate Temperatures	http://itqmembranes.itq.webs.upv.es/

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REMEB	H2020-EU.3.5.4.	ECO-FRIENDLY CERAMIC MEMBRANE BIOREACTOR (MBR) BASED ON RECYCLED AGRICULTURAL AND INDUSTRIAL WASTES FOR WASTE WATER REUSE	http://www.remeb-h2020.com
REMIND	H2020-EU.1.3.3.	Renewable Energies for Water Treatment and REuse in Mining Industries	
ReSpirA	H2020-EU.3.5.;H2020-EU.2.3.1.	Olive oil wastewater Reuse for the production and commercialisation of Spirulina Alga	https://blog.greentechsrl.com/2016/05/30/respira-olive-oil-wastewater-reuse-for-the-production-and-commercialisation-of-spirulina-alga-2/
ReWaCEM	H2020-EU.2.1.5.3.	Resource recovery from industrial wastewater by cutting edge membrane technologies	http://www.rewacem.eu
REWAISE	H2020-EU.3.5.4.;H2020-EU.3.5.2.2.	REsilient WAter Innovation for Smart Economy	http://rewaise.eu/
REWATERGY	H2020-EU.1.3.1.	Sustainable Reactor Engineering for Applications on the Water-Energy Nexus	
RIBATI	H2020-EU.3.5.;H2020-EU.2.3.1.	Radically innovative bacterial treatment for recalcitrant industrial wastewater	http://www.amapex.net
SALTGAE	H2020-EU.3.5.4.	Demonstration project to prove the techno-economic feasibility of using algae to treat saline wastewater from the food industry.	http://www.saltgae.eu
Saraswati 2.0	H2020-EU.3.5.4.;H2020-EU.3.5.2.2.	Identifying best available technologies for decentralized wastewater treatment and resource recovery for India	https://projectsaraswati2.com
SHEPHERD	H2020-EU.3.3.;H2020-EU.2.1.1.;H2020-EU.2.3.1.	Energy-Efficient Activated Sludge Monitoring for Wastewater Treatment Plants	http://www.shepherdproject.eu

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SIM4NEXUS	H2020-EU.3.5.4.	Sustainable Integrated Management FOR the NEXUS of water-land-food-energy-climate for a resource-efficient Europe	http://sim4nexus.eu/
SLIGHT GRANULATION	H2020-EU.3.5.;H2020-EU.2.3.1.	SLIGHT GRANULATION process reducing Water consumption in ceramic tiles industry	http://www.manfredinieschianchi.com/
SmartTap	H2020-EU.1.1.	Real-Time Monitoring System for Water Quality	
SOFI-PP	H2020-EU.3.5.;H2020-EU.2.3.1.	Sofi Filter Novel Method for Power Plant Water Treatment	http://www.sofifiltration.com
SolardeSaLt	H2020-EU.3.5.;H2020-EU.2.3.1.	A Renewable Approach for Industrial Water Desalination by using Hybrid Photovolt	http://www.hydroitalia.com/
SPOTVIEW	H2020-EU.2.1.5.3.	Sustainable Processes and Optimized Technologies for Industrially Efficient Water Usage	http://www.spotview.eu/
SuPER-W	H2020-EU.1.3.1.	Sustainable Product, Energy and Resource Recovery from Wastewater	https://www.superw.ugent.be/
TANNOW	H2020-EU.3.5.;H2020-EU.2.3.1.	Reuse of Olive Mill Wastewater for producing new antioxidant tanning chemicals	http://www.archa.it/en-US/Portfolio
THOR	H2020-EU.3.3.;H2020-EU.2.1.1.;H2020-EU.2.3.1.	CONTINUOUS MONITORING SYSTEM FOR REAL-TIME DETECTION OF WATER HAMMER AND REDUCTION OF WATER LEAKAGES	http://www.teclab.net/index.html
ToxMate	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	ToxMate: Automated on-line and real-time monitoring of wastewater toxicity with ToxMate	http://www.viewpoint.fr/en/single/news/discover-our-brand-new-toxmate-for-ecotoxicology-environmental-toxicology-and-ecology-analysis
ToxMate	H2020-EU.3.;H2020-	Continuous real-time monitoring of water toxicity	

Acronym	Programme	Title	Project Link
	EU.2.3.;H2020-EU.2.1.		
TreatRec	H2020-EU.1.3.1.	Interdisciplinary concepts for municipal wastewater treatment and resource recovery. Tackling future challenges	http://treatrec.eu/
ULTIMATE	H2020-EU.3.5.4.;H2020-EU.3.5.2.2.	ULTIMATE: indUstry water-utiLiTy symbIosis for a sMarter wATer society	
UNTWIST	H2020-EU.1.3.2.	UNraveling the knoT of the Water-energy-food nexus usIng ecosySTems services	
UVMWREACT	H2020-EU.1.3.2.	Design, fabrication and optimization of a novel integrated UV-microwave assisted catalytic reactor for the continuous flow treatment of wastewater	http://www.dmu.ac.uk/uvmwreact
UVT	H2020-EU.2.3.1.;H2020-EU.3.2.	UV cleaning for beverage tanks eliminating the need for water and chemicals	http://www.bluemorphuv.com
Waste2Fresh	H2020-EU.2.1.5.3.	Smart innovative system for recycling wastewater and creating closed loops in textile manufacturing industrial processes	
Water2REturn	H2020-EU.3.5.2.3.;H2020-EU.3.5.4.;H2020-EU.3.5.2.2.	REcovery and REcycling of nutrients TURNing wasteWATER into added-value products for a circular economy in agriculture	http://www.water2return.eu
WATER-MINING	H2020-EU.3.5.4.;H2020-EU.3.5.2.2.	Next generation water-smart management systems: large scale demonstrations for a circular economy and society	
WATERSIGN	H2020-EU.3.;H2020-EU.2.3.;H2020-EU.2.1.	WATERSIGN: Smart Water Monitoring & Leakage Detection	http://www.watersign.co.il
WATERSPOUTT	H2020-EU.3.5.4.	Water - Sustainable Point-Of-Use Treatment Technologies	http://www.waterspoutt.eu
WaterWorks2015	H2020-EU.3.5.4.	Water Works 2016-2020 in Support of the Water JPI (WaterWorks2015) - Sustainable water use in agriculture, to increase water use efficiency and reduce soil and water pollution	http://www.waterjpi.eu/index.php

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WaterWorks 2017	H2020-EU.3.5.2.2.	Water Works 2018-2022 in Support of the Water JPI (WaterWorks2017) and of the EC Call SC5-33-2017: Closing the water cycle gap	http://www.waterjpi.eu/implementation/supporting-projects/waterworks2017
WIDER UPTAKE	H2020-EU.3.5.4.;H2020-EU.3.5.2.2.	Achieving wider uptake of water-smart solutions	
WIDEST	H2020-EU.3.5.4.	Water Innovation through Dissemination Exploitation of Smart Technologies	http://www.widest.eu/
ZERO BRINE	H2020-EU.3.5.4.	Re-designing the value and supply chain of water and minerals: a circular economy approach for the recovery of resources from saline impaired effluent (brine) generated by process industries	https://zerobrine.eu/