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PhD Programme in Innovation for the Circular Economy -
XXXIV Doctorate Cycle

Water: circular economy barriers and opportunities

Doctoral Thesis by Ilaria Schiavi

April 2023

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DEDICATION

To Angelo and Vanna, for always supporting my choices no matter what.

To Remo, for the unlimited patience.

And above all, to Lavinia.

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EXECUTIVE SUMMARY

With useable freshwater being such a scarce resource, contended by many, it has become apparent the need to ensure its use is managed under the lens of the circular economy approach Currently, the most common application of the circular economy framework to water is focusing mainly on the recovery of water from urban waste water treatment plants. This aspect is also regulated at EU level with Regulation 2020/741 on minimum requirements for water reuse, which establishes quality parameters and a risk-based approach for the use in agriculture of reclaimed water issued from urban waste water treatment plants. Further opportunities for recovery of materials suspended in used urban water are being explored by many research and innovation projects and are advocated also by European institutions.

Circular economy of water, however, goes beyond the simple recovery of "waste" water, to implement better management of water resources and extended life of the resource itself in the technological cycle. The risk-based approach proposed by Regulation 2020/741 should be mirrored by a "fit for purpose" approach, which entails a different understanding of water as a material/resource whereby the application drives the selection of the water to be used. In this, factories from many sectors could open up to the sourcing of alternatives to mains water, which is very often overengineered with respect to many industrial applications. To this end, standardisation is supporting industry best practice, for example through the publication of reference specifications for water reuse in selected applications (to date: cooling circuits). By adopting this fit for purpose approach, supported by innovative technologies able to deliver small scale, specialised treatment, use of alternative sources of water can be implemented at low environmental and economic costs, be it reclaimed water, water in closed loops or cascading loops. This looping approach also opens up opportunities for recovery of suspended materials and/or use of enhanced reclaimed water containing compounds beneficial for the processes.

There is a shift in policy making required: the water policy acquis developed since the 1970s is not aligned with circular economy policy. First of all, it is concerned mostly with water <u>quality</u> in the environment, with little consideration for water <u>quantity management</u>, despite water scarcity now interesting many parts of Europe, as an effect of climate change and increased pressures from sectors such as irrigated agriculture. The first policy instruments being reviewed in light of the Green Deal are the Urban Waste Water Treatment Directive and the Sewage Sludge Directive. However, the recast proposed for the first one does not push enough towards full integration of circular economy, while for the second results of the consultations are still not available at the time of writing. The Water Reuse Regulations issued in 2020

constitute a first piece of circular economy -led legislative instrument, recognising a practice already implemented by many Southern Europe Member States; however, more can be done.

Finally, industry is voicing its concerns and innovation needs through a number of public private partnerships (PPPs) with the EU, the most active being the one strictly related to water, Water4ALL. In its Strategic Research and Innovation Agenda, water in the circular economy is considered amongst the expected impacts; amongst the other PPPs, the most considered of water in the circular economy are the Process4Planet (process industries) and Circular Bioeconomy (bioeconomy industries including agriculture, food processing and chemicals). The most active stakeholder is WaterEurope, the European Technology Platform that associates European's water stakeholders and that is pushing for: a water smart society where the value of water drives its sustainable and efficient use; closed loop uses in processing; integration of natural based solutions; innovative governance. The above PPPs contribute to driving the R&I agenda of Horizon Europe, therefore enabling the demonstration of innovative approaches and solutions which could influence future policy making.

The thesis presented describes the work undertaken within the industrial PhD programme "Innovation for the circular economy" – XXXIV cycle. The subject matter is the main concept around which Horizon 2020 project "Project Ô - Demonstration of planning and technology tools for a circular, integrated and symbiotic use of water" (Grant Agreement 776816, 2018-2022) was developed and started. Project Ô is coordinated by IRIS srl, where the author was employed as project manager when this PhD was started.

1 INTRODUCTION

With useable freshwater being such a scarce resource, contended by many, it has become apparent the need to ensure its use is approached under the lens of the circular economy (CE) approach (Fidelis, et al., 2021). This thesis considers the application of the Circular Economy framework to water and analyses barriers to and opportunities for its implementation. Industrial practices, standardisation, the water legislation framework and current research, all contribute to supporting the switch from a linear to a circular approach in water management. However, some barriers exist on the path of full exploitation of the opportunities: the water regulatory framework is changing slowly, while the technical aspects for ensuring implementation of a "circular water" are still being explored, also through EU research and innovation. Additional driving forces derive from the twin decarbonisation and digital transitions, which affects water governance in the context of climate change adaptation and application of digitalisation to water management.

The main research question addressed within this thesis is how does the framework of circular economy apply to water and what are the opportunities and barriers for furthering its application.

This thesis therefore consider:

- Application of the circular economy framework to the water resource:
    - Definitions and applicability according to literature;
    - Circular economy of water in practice: the current focus on urban waste water;
    - Opportunities for industrial waste water and overall changes in approaches required to support a full implementation of the circular economy paradigm; and
    - Existing research and innovation on the issue of water in the context of the circular economy, underpinning through demonstrators many of the concepts expressed.
- Regulatory aspects, focusing on current and upcoming EU policy and regulatory documents on water:
    - How does it intersect circular economy policy and framework, identifying barriers and exploring also opportunities for further policy making;
- Industrial policies driving future research, which incorporate aspects of circular economy of water, including some of those proposed in the first chapter.

By reviewing how currently circular economy is applied to water, in the established regulations and practices and in the innovation closest to market, it is possible to highlight where a change in approach could be needed and what are the main barriers to be overcome.

2 WATER AND THE CIRCULAR ECONOMY

2.1 WATER AND THE DEFINITION OF CIRCULAR ECONOMY: CURRENT APPLICATIONS AND POSSIBLE EXTENSIONS

Circular economy has had many valid definitions, from institutions, scholars and practitioners (Kirchherr, Reike, & Hekkert, 2017). At political level, the first CE Action plan (European Commission, 2015) defined circular economy as an approach where "*the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised, [...] an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy.*" (European Commission, 2015). COM (2019) 640 – the Green Deal (European Commission, 2019) and the consequent new CE Action Plan (European Commission, 2020) extended this definition into "*a 'sustainable products' policy to support the circular design of all products based on a common methodology and principles, prioritising reducing and reusing materials before recycling them, fostering new business models and setting minimum requirements to prevent environmentally harmful products from being placed on the EU market*". This is complemented by an urgent call "*to accelerate the transition towards a regenerative growth model that gives back to the planet more than it takes, to advance towards keeping its resource consumption within planetary boundaries, and therefore to strive to reduce its consumption footprint and double its circular material use rate in the coming decade*".

Although not so explicitly declared, **the circular economy framework is fully applicable to water**; however, many researchers (and policy making, see section 2.3.1 below) have focused on the application of the framework to **water from urban waste water only** (Sauvé, Lamontagne, Dupras, & Stahel, 2021), in a parallel approach to circularity for materials, readily and more widely applied to waste.

Some researchers have proposed the application of the 6Rs to waste water (rethink, reduce, remove, reuse, recycle, recover- (Smol, 2020), while others are driving, through research, a more holistic view on the recovery of value from waste water, which includes energy, recovery of nutrients and other materials as well as recovery of clean water (Fatone, Loederer, Wintgens, Álvarez Rodríguez, & Hospido, 2017)- this will be further analysed in section 2.3.2.

There is however **scope for extending the applicability of the circular economy framework to other areas of water management than waste water**. The "Water and Circular Economy White paper" by the Ellen MacArthur Foundation (Ellen MacArthur Foundation; Arup; Antea Group, 2019) takes indeed a broader view on the application of circular economy to water. This is derived from the Foundation's definition of circular economy, and it is demonstrated by matching its principles with water system applications as shown in **Errore. L'origine riferimento non è stata trovata.** below. This approach demonstrates how the circular economy framework applies to the whole area of water management, over and above waste water, so it goes in the direction of the research question of this thesis.

Table 1 Matching of circular economy principles with applications in water systems, from (Ellen MacArthur Foundation; Arup; Antea Group, 2019)

Circular economy principles	**Application to water systems**
Design out waste and externalities	Optimisation of the amount of energy, minerals, and chemicals use in the operation of water systems in concert with other systems. Optimisation of consumption of water within a sub-basin in relation to adjacent sub-basins (e.g., use in agriculture or evaporative cooling). Use of measures or solutions which deliver the same outcome without using water.
Keep resources in use	Optimisation of resource yields (water use and reuse, energy, minerals, and chemicals) within water systems. Optimisation of energy or resource extraction from the water system and maximise their reuse. Optimisation of value generated in the interfaces of water systems with other systems.
Regenerate natural systems	Maximisation of environmental flows by reducing consumption and non-consuming uses of water. Preservation and enhancing of the natural capital (e.g., river restoration, pollution prevention, quality of effluents, etc.). Ensuring minimum disruption to natural water systems from human interactions and use.

The same 2019 White Paper also considers three dimensions of water onto which to apply the circular economy principles:

- Water as a service: consumptive, production and process use;
- Water as a carrier: nutrients, chemicals, minerals;
- Water as a source of energy: kinetic, thermal and bio-thermal.

This approach can be further explored and for this reason, a step back to the definition of circular economy is taken to reconsider how to apply it to water. At the same time, a redefinition of water (asset vs service) and changes in approaches are proposed and verified to support and widen the application of circular economy principles to water.

2.2 FURTHERING THE APPLICATION OF THE CIRCULAR ECONOMY PARADIGM TO WATER

Amongst the many definitions of circular economy (Kirchherr, Reike, & Hekkert, 2017), the Ellen McArthur Foundation definition is chosen for further analysis. This specific definition characterises the circular economy as "*as an economy that is restorative and regenerative by design and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. It is conceived as a continuous positive development cycle that preserves and enhances natural capital, optimises resource yields and minimises system risks by managing finite stocks and renewable flows*". This definition includes and focuses on "*extending the use cycle length of an asset, increasing utilisation of an asset or resource, looping or cascading an asset through additional use cycles, and regeneration of natural capital*" (Ellen MacArthur Foundation, 2016) and (Ellen MacArthur Foundation, 2019).

How does this definition apply to water? First of all, it is considered that the "service" attribute often given to water might distract from the fact that **water has a materiality and a value as substance itself and that there is a very finite quantity of useable water,** despite the fact that it is replenished through its natural cycle (Sauvé, Lamontagne, Dupras, & Stahel, 2021). The 2021 UN World Water Development Report "Valuing Water" (UNESCO, 2021) analyses the value or worth of water and identifies it as a **unique and non-substitutable resource of limited quantity**. Indeed, it is believed that, despite the large quantity of water on our planet, 97% is saltwater, leaving only 3% as freshwater, approximately 1% of which is readily available for use, the rest being "trapped" e.g., in glaciers and polar ice caps (NASA, 2021). Water limitedness, however, is not recognised widely enough. For this reason, this thesis considers that the "resource" or "asset" dimension of water should be part of the current conception of water alongside, or instead of, its "service" dimension.

With this in mind, the framework of circular economy, derived from the Ellen MacArthur Foundation definition, fits water very well. It is true that a complete parallel between water and materials and/or products cannot be done; however, the following considerations apply:

- Despite not being a product as most commonly intended, i.e., a manufactured or shaped object, made of one or multiple materials, water requires much energy, time and money to reach quality required for its applications e.g., for drinking. This is relevant when considering how often water is overengineered for its applications (see section 0);
- Water can be a material or a component, for example, when incorporated into e.g., foodstuff, medicines, cosmetics or detergents. Most often, it plays an important part in the processing that transforms materials into products. In this case it provides a "service" (e.g., cleaning and cooling) but, unlike energy, it does not transform into lower,

not easily recoverable forms (i.e., heat). Water keeps its materiality; hence it deserves to be kept at its "highest utility and value at all times". This justifies the looping approach in high value applications.

- Water enters both the biological and the technical loops mentioned in the definition, and flows between the two, carrying materials and energy. This flow, however, needs to be controlled on the technical side, to avoid loss of value (i.e., loss of substances suspended in "waste" water[1]). The link to the biological side needs to be better understood to fully sustain the various nexus, e.g., water-soil-food; water-biodiversity-food etc.
- Although it is a renewable resource because of the hydrological cycle, there is only a limited amount of water truly available. Aside from the geophysics of water on our planet, water quality is deteriorating overall with well-known and emerging contaminants that cannot be removed by current water treatments and are cumulating in the environment and in the different water sources. As "truly clean" water becomes scarce – and uncontaminated water even rare - ecosystems suffer and can no longer offer required good and services (over and beyond water itself); drinking water becomes more costly to obtain; soil and food quality diminish and human health is jeopardised.

This thesis therefore explores the sourcing and the "keeping in use" principles of the White Paper (Ellen MacArthur Foundation; Arup; Antea Group, 2019). Alternative definitions exist with respect to circularity: Sauvé (Sauvé, Lamontagne, Dupras, & Stahel, 2021) introduces a concept of "circular water" as "consumption of water that is in a closable loop, i. e, the whole process or water harvest and recuperation can be repeated ad infinitum without loss of the water resource or its contamination". This concept is strongly linked with an assessment of water footprinting, and it considers circular water as being sustainable with limited impact.

[1] Reasons for the adoption of quotation marks for "waste" water are given below in BOX 1.

2.3 CIRCULAR ECONOMY APPLIED: URBAN WASTE WATER

2.3.1 Existing regulated approaches to circular economy of water: reuse of water from urban waste water

The analysis of the EU policy (chapter 3 below) will show that water policy so far has focused mostly on the qualitative aspects of water, with water quantity issues being approached mostly in the framework of water scarcity and/or effects of climate change, i.e., the need to balance water pressures with (natural) water availability, and flood management. On the other hand, economic drivers have pushed the first regulated applications of circular economy for water, i.e., the use of treated "waste" water for irrigated agriculture. This is often a recognition of a *de facto* or unplanned use of treated "waste" water, which is a significant input of many rivers from where farmers take water for crops irrigation, particularly in the South of Europe where agriculture cannot rely only on (scarcer and scarcer) rain. A planned reuse had been regulated by EU Member States since a long time and it has recently been regulated at EU level (see section 3.3.1). **This can be said representing the first alignment of water policy with the circular economy framework**. An extension of this approach to the whole "waste" water management might follow (see section 2.3.2); furthermore, many water-related Directives have been earmarked for review under the lens of the circular economy framework.

BOX 1 "Waste" water?

Circular economy is, at least conceptually and tendentially, doing away with "waste" ("any substance or object which the holder discards or intends or is required to discard" (European Parliament and the Council, 2018)) as the "discarding" is no longer contemplated for resources in any circular economy definition. While "waste" water does not have the same stringent definition as waste (see below), it still needs treatment in a waste facility, i.e., the waste water treatment plant. Considering it under the circular economy lens, however, "waste" water is nothing else but water carrying interspersed/solute substances (Ellen MacArthur Foundation; Arup; Antea Group, 2019). Some of these substances might be valuable and therefore of interest for their recovery through separation from the carrier or key in characterising a reusable water for a specific application (e.g., water carrying a salt that can be used as catalyst in some processes). This review of the concept of "waste" water has been proposed already in Europe at political level (e.g., (JRC, 2012) and in Regulation 2020/741), it is being supported by research (see sections 2.3.2 and 0) and might be further driven by industrial water reuse standards (e.g., ISO 22447:2019 (ISO, 2020)) and by the need to further explore the many nexus of water, in particular water/energy/food/ecosystems (Nika, et al., 2022). These all drive towards the acknowledgement that "waste" water might be an old fashioned and counterproductive way of thinking and talking about (used) water.

The definition of waste and other parallelisms between materials and water

The term "waste" is uniquely defined within the Waste Framework Directive (as amended) (European Parliament and the Council, 2018) as "any substance or object which the holder discards or intends or is required to discard". This definition applied to materials determine how they must be dealt with to ensure protection of human health and the environment. The Directive defines some fundamental criteria driving the overall waste and waste management policy of the EU:

- The "polluter pays principle" by which "the costs of waste management, including for the necessary infrastructure and its operation, shall be borne by the original waste producer or by the current or previous waste holders".
- The "extended producer responsibility", which applies to "any natural or legal person who professionally develops, manufactures, processes, treats, sells or imports products (producer of the product)" and expects that "they undertake financial or financial and organisational responsibilities for the management of the waste stage of a product's life cycle".
- The hierarchy of waste management: this establishes how waste should be first of all prevented, and then the preferred options for its management;
- The End-of-waste criteria, i.e., how and when waste ceases to be waste and becomes a product, or a secondary raw material.

The above fundamental principles have influenced heavily approaches such as sustainable production and consumption, eco-design of products, industrial symbiosis, circular economy itself. They have been also both barriers and drivers. With regards to circular economy, the Waste Framework Directive is being revised in light of the adoption of the Green Deal and the (new) Circular Economy Action Plan. The public consultation on the revision of the Waste Framework Directive closed in August 2022 and, at the time of writing, a revised version is being prepared for adoption in 2023.

Waste water is specifically excluded from the scope of the Waste Framework Directive[2], hence the same opportunities and barriers do not extend to waste water. Some parallelism can be found, as well as some differences. The Water Framework Directive (European Parliament and Council of the European Union, 2000) is the reference Directive for water policy at EU level, so it has a larger remit than the Waste Framework Directive. Urban waste water is the specific object of the Urban Waste Water Treatment Directive (UWWTD) (Council of the European

[2] Although the European Court of Justice (CJEU) questioned this exclusion, as substances are excluded only "to the extent that they are covered by other community legislation". CJEU found that Directive 91/271/EEC, the Urban Waste Water Directive, not to be "other legislation within the meaning of waste legislation because such legislation should include precise provisions organising its management as waste and ensuring a level of protection which is at least equivalent to that resulting from waste legislation." In other words, the CJEU considered that Directive 91/271/EEC does not ensure such a level of protection. (Academy of European Law (ERA), year not available).

Union, 1991). The UWWTD establishes requirements with respect to the collection, the treatment, and the discharge of urban waste water and the treatment and discharge of waste water from certain industrial sectors by combining quality objectives and emission limit values. Neither the Water Framework Directive nor the UWWD provide a definition of waste water as stringent as that of "waste". This definition has not been required at law-making level at least to date. However, the Water Reuse Regulations (European Parliament and the Council, 2020) provide a definition of "reclaimed water", i.e., "urban waste water treated in compliance with the requirements of the UWWTD and resulting from a further treatment in a facility that produces water fit for a use specified within Annex 1 of the same Regulations, i.e., fit for irrigating a certain category of crop amongst those indicated". On the merits of this fit for purpose approach see section 0.

A water hierarchy also exists (see BOX 7) regarding the approach of the use of water.

The UWWTD has undergone an evaluation in 2019. Alongside effectiveness, efficiency, coherence, and EU added value, the evaluation covered relevance including with respect to the circular economy. The findings of the consultation confirm that **the Directive does not align with circular economy principles**, with nearly half of the respondents believing that the UWWTD does not promote safe water reuse, sustainable approaches such as phosphorus and nitrogen recycling, and safe sludge reuse, and that, on the subject of overall sludge reuse, the Directive is not compatible at all (European Commission, 2019). A proposal for a revised UWWTD was published at the end of October 2022 (European Commission, 2022)- see also section 3.4.

2.3.2 Other opportunities for applying the circular economy approach to urban waste water

Aside from reuse of treated "waste" water, policy making is considering the whole "waste" water management as the next window of opportunity for circular economy application.

Looking at other components of "waste" water, current regulatory instruments consider the use of the residue from the treatment of "waste" water, i.e., sewage sludge. This is regulated through the Sewage Sludge Directive 86/278/EEC (Council of the European Communities, 1986), which guides one of the most common recovery routes for treated sewage sludge, i.e., land spreading, particularly on agricultural land. This practice enables the direct recovery of nutrients concentrated in the sludge, particularly phosphorus and nitrogen – bearing in mind the requirements of the Nitrates Directive (Council of the European Union, 1991) and potential issues regarding heavy metals contamination.

However, opportunities for circular thinking exist over and beyond the "simple" spreading of sewage sludge on land, with potential for mitigating risks from contamination (e.g., (Smol, 2020)). At global level, the United Nations World Water Development report 2017 (UNESCO World Water Assessment Programme, 2017) emphasized the role of "waste" water in the circular economy and it presented the ideal "waste" water management cycle as an integrated 4-step process: (a) source reduction and prevention of pollution, (b) contaminants removal, (c) waste water re-use and (d) by-products recovery. At EU level, the European Environment Agency report "Beyond water quality — Sewage treatment in a circular economy" (European Environment Agency, 2022) recognises the role of many water utilities that, in the drive to reduce their energy consumption, have explored innovative approaches to drive resource efficiency and circularity into their - currently - linear service provision (the "cleaning" of "waste" water prior to re-issuing to the environment). Many research and innovation projects funded through the last R&I framework programmes such as Horizon 2020 (see Annex I), have also explored how "waste" water treatment plants can actually be transformed into resource hubs/ biorefineries issuing:

- water suitable for reuse/release into the natural environment and
- nutrients and secondary raw materials derived from treatment of:
    - sewage sludge and
    - residues of pre-treatments (e.g., screening, degreasing) and
    - residues of tertiary treatments (e.g., membrane treatments).

This approach is fully in line with a redefinition of "waste" water and disposal parallel to the terminology used for (other) wastes (see BOX 1 above). To introduce this approach into policy, a few stakeholders (e.g., (Water Europe, 2021) have called upon a review[3] of the Sewage Sludge Directive in light of the adjoining strategies of the new Circular Economy Action Plan (European Commission, 2020) but also the Farm2Fork (European Commission, 2020), and EU Soil (European Commission, 2021) strategies.

BOX 2 Recovery of resources from urban waste water – H2020 Project SMARTPlant

Project "SMART PLANT- Scale-up of low-carbon footprint MAterial Recovery Techniques in existing waste water treatment PLANTs" (Horizon 2020, Grant Agreement nr. 690323) demonstrated the recovery of precursors and their processing to ready-to-market products such as biopolymers, cellulose, fertilizers and intermediates. The technological solutions for direct recovery and further processing were implemented in five municipal water treatment plants, and were optimised also for environmental impact, including energy efficiency and reduction of greenhouse gas emissions. The solutions were also evaluated in a cost and benefit

[3] The Sewage Sludge Directive is already under review for a modernisation of its remit, in particular on the regulatory aspects on 'emerging contaminants' like pharmaceuticals and microplastics. Already the Directive prescribes maximum concentration limits of heavy metals to avoid soil and crops contamination. Pollutants are indeed a barrier to the recovery of any resource from waste water, according to the fundamental principle of protection of human health and the environment. The EEA Report recognises the need for a structural effort of prevention, in line with the zero-pollution objective of the Green Deal.

analysis and social impact assessment (Foglia, et al., 2021) that demonstrated the economic advantages of the technology proposed, primarily in terms of sludge treatment savings, then in terms of energy and carbon efficiency and ultimately in terms of material recovery and reuse.
Overall, the solutions proposed provide operational savings to the WWTPs because of reduced aeration energy, less chemical use and smaller quantities of sludge to be disposed of. Indeed, savings in sludge disposal costs and energy costs are the main drivers for adoption, with additional revenues from the sale of recovered resources. The project also identified opportunities for public private partnerships in the processing of recovered resources connecting the water sector to the chemical industry and its downstream segments such as the construction and agricultural sector, implementing well-structured examples of industrial symbiosis and breaking the barriers between public and private. The project above contributes to the switch from "waste" water treatment plant concept to a water resource recovery facility (Fatone, Loederer, Wintgens, Álvarez Rodríguez, & Hospido, 2017), which is fundamental for a circular economy of (waste) water.

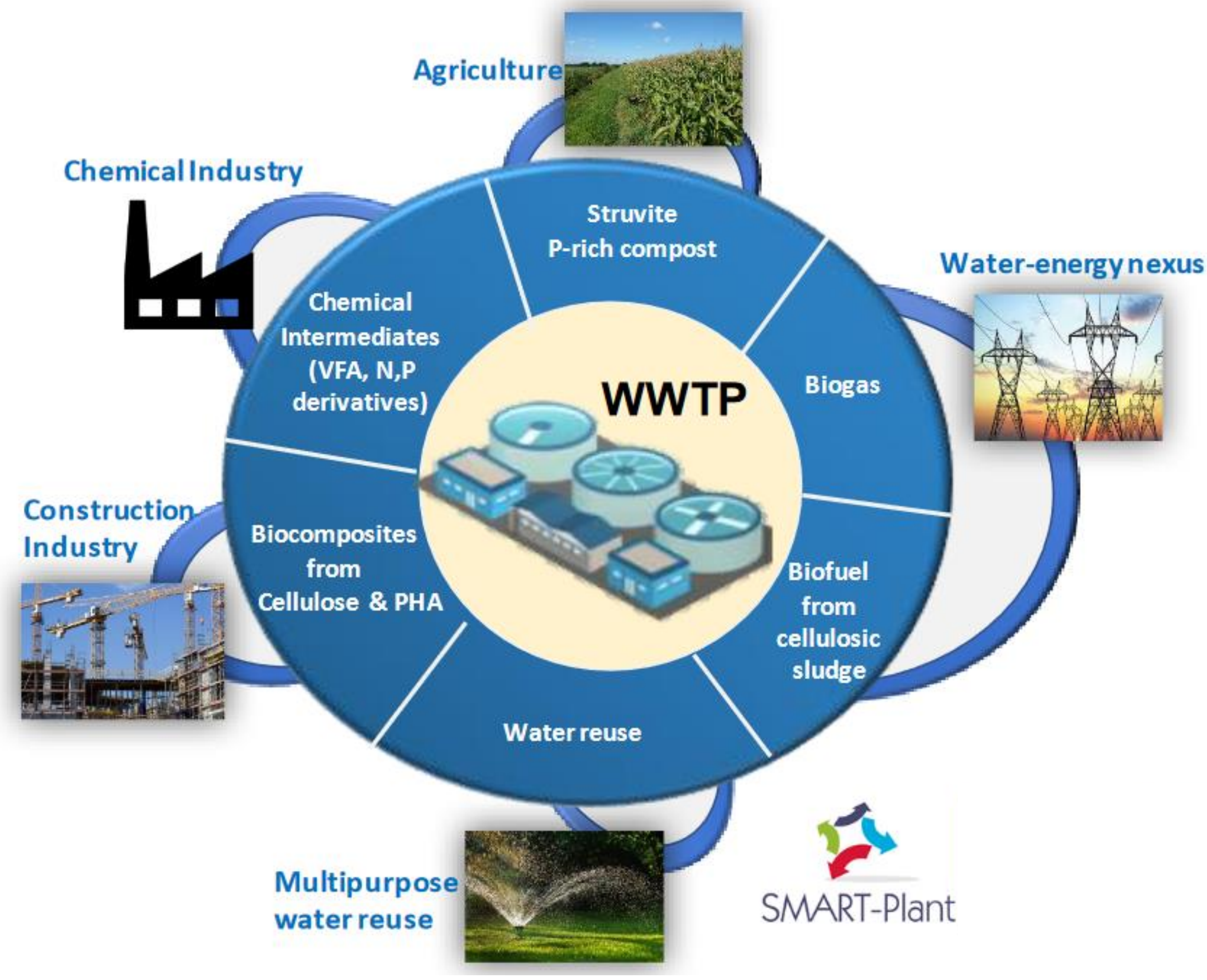

Figure 1 A representation of the multiple recovery options explored by the SMART-Plant project.

Aside from treatment of "waste" water, other opportunities for circular economy interventions are available with regards to "waste" water through **alternative management**. Indeed, the EEA report (European Environment Agency, 2022) calls upon the enhancement of recycling opportunities deriving from separating flows of "waste" waters at least from civil outlets, i.e., grey waters from brown waters: this is another parallel with waste management and source segregation of waste to facilitate recycling/recovery. Recognising the costs (mostly infrastructure) implicit in adapting our current system to enable this segregated collection, the report highlights the potential of nature-based solutions and the opportunity to implement **small, localised loops of water treatment** (see BOX 3 below and, further on, section 2.4.1).

BOX 3 Segregated collection and nature-based solutions for recovery of value from urban waste water: H2020 projects RUN4LIFE and HYDROUSA

Project RUN4Life - "Recovery and Utilization of Nutrients 4 Low Impact FErtiliser" (Horizon 2020, Grant Agreement nr. 730285) proposes a source-separated collection of domestic waste waters and kitchen waste, with each flow receiving optimal treatment for resource recovery and subsequent safe reuse. The project introduces innovative ultra-low flush vacuum system for vacuum toilets to reduce the flow of brown waters (this is also a water minimisation measure), also identifying improvements in safe nutrient recovery treatments deriving from the lowered dilution and addition of organic waste (anaerobic digestion). Separated grey water are treated and disinfected for reuse in agriculture, for toilet flushing and for industry. The different flows are treated in decentralised systems and the water and nutrients recovered are used locally to the site. The project considers decentralised plant beneficial for small communities and new developments in a scenario where reclaimed water, organic matter and energy (biogas) can be used directly in the vicinity of the treatment plant, compared with a scenario where the treatment is undertaken in a centralised plant and reclaimed water is pumped to reach its users (Estévez, González-García, Feijoo, & Moreira, 2022). **This supports the small loops of water treatment approach.**

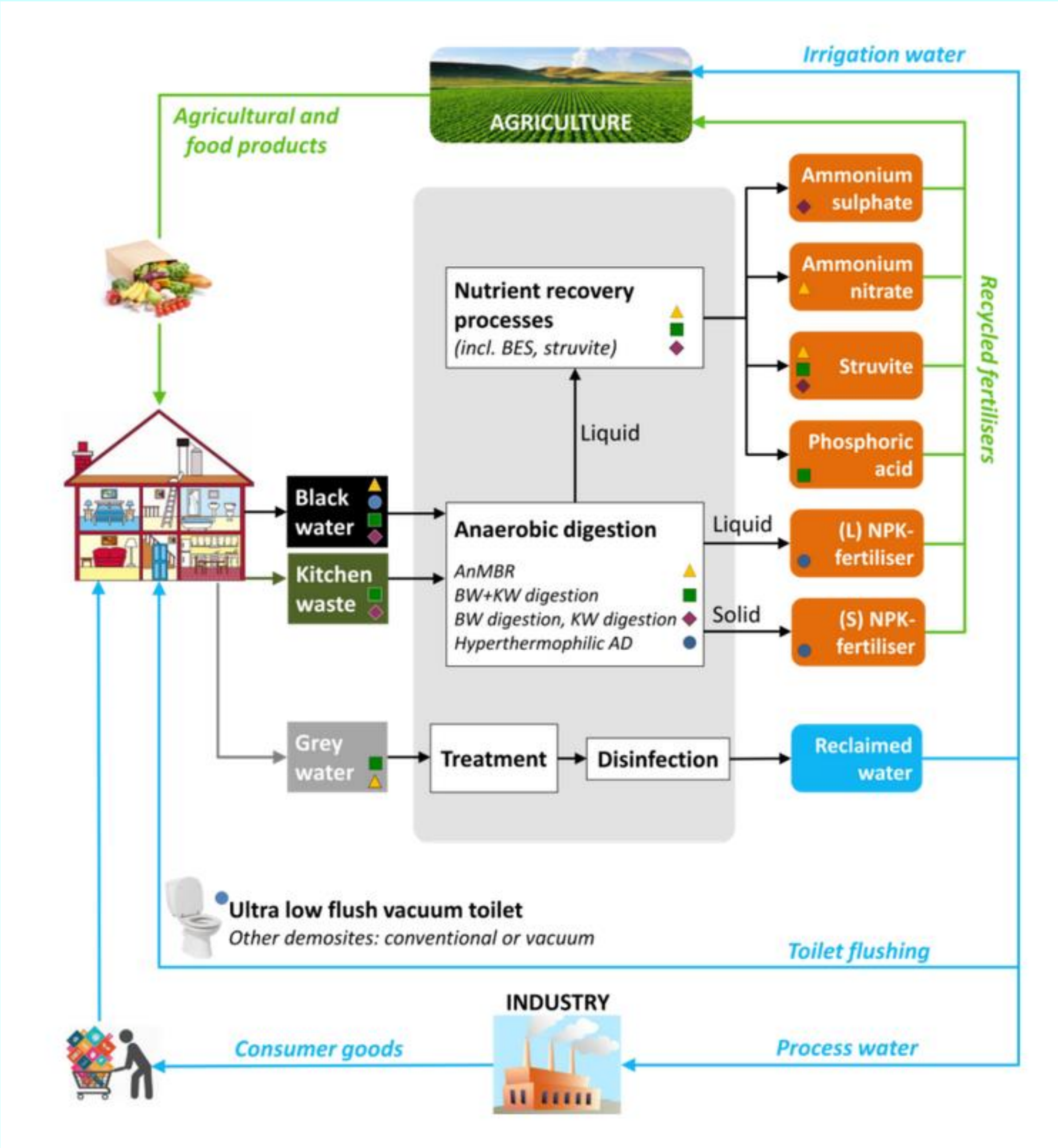

Figure 2 A representation of the approach proposed by the Run4Life project

HYDROUSA project (Horizon 2020, Grant Agreement nr. 776643) focuses on tailored solutions for water-scarce regions. It aims to provide innovative nature-based and nature-inspired solutions for decentralized water/wastewater treatment and management. The cycles to be closed include water, materials and energy, through exploring the nexus water/soil and water/energy. Nature-based solutions are chosen as a low energy alternative to technological solutions and for direct recovery:

- for waste water treatment**:**
  constructed wetlands, enhanced through aeration and electro-activation and coupled with Up-flow Anaerobic Sludge Blanket and compost cultivator**;**
- for water supply:
  stormwater aquifer recharge, rainwater storage; mangrove still desalination, humidity

condensation.

The demonstration and replication sites are mostly island communities, who are highly involved in the definition and running of the decentralised solutions. The local communities are at the centre of the project's conception, as it can be seen from the picture below, and they reap the benefits of the services provided by the circular solution, from fresh water to methane to food and high value products. **This also supports small loops of water treatment approach.**

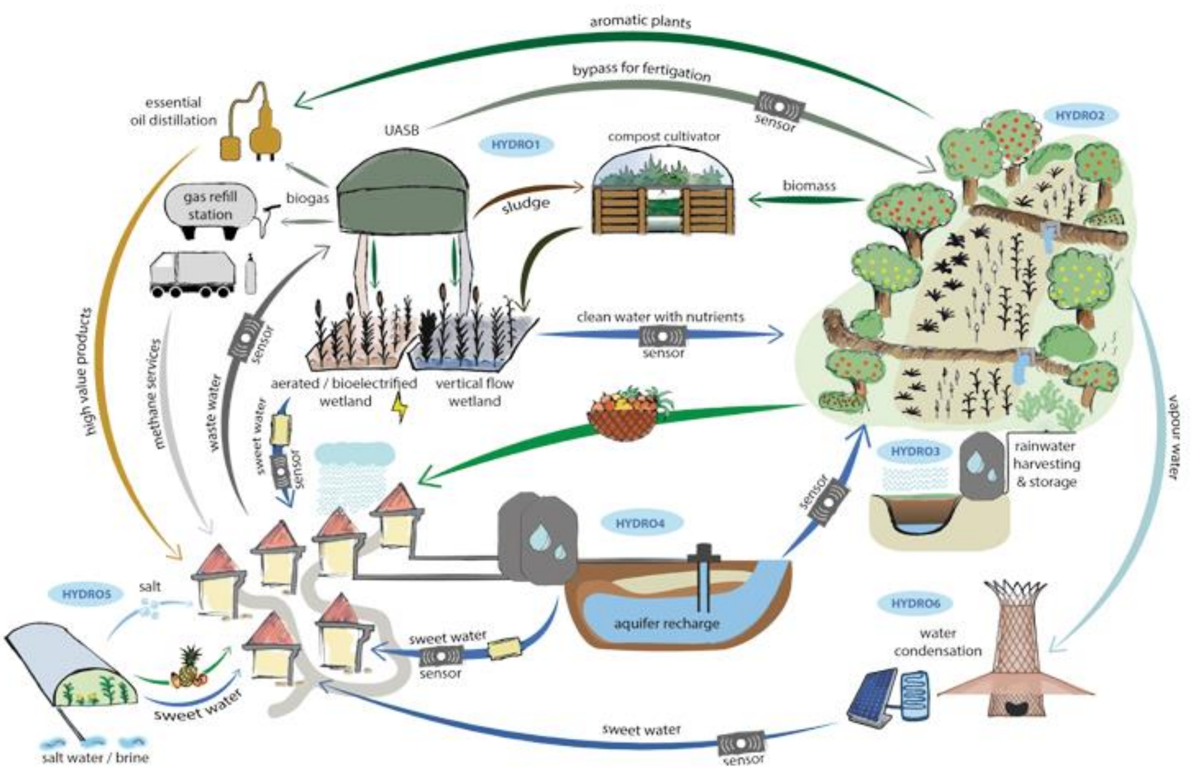

Figure 3 An overview of the innovative solutions introduced by the Hydrousa project and the flows of materials, energy, food and water created

The coupled solutions HYDRO1 (UASB + enhanced constructed wetland) and HYDRO2 (agroforestry) have been used to validate an extended Multi-Sectoral Water Circularity Assessment (Nika, et al., 2022), which evaluates circularity of complex systems under the Water-Energy-Food-Ecosystems (WEFE) nexus. This framework can be seen alternative to an LCA and LCC analysis and includes a methodology for the selection of indicators, which are also related to the Sustainable Development Goals. It has the advantage of being applicable both for initial benchmarking and for dynamic assessment, including evaluation of impacts of operational changes. This latter feature, applied to the HYDROUSA case, highlighted its positive circularity performance, but also optimisation opportunities and circularity risks to be mitigated (Nika, et al., 2022).

2.4 CIRCULAR ECONOMY OPPORTUNITIES BEYOND URBAN WASTE WATER

The sections before have shown how circular economy has so far intersected successfully the management of urban waste water, a priority area given the large quantities of water available and/or the overall homogeneity of the sector (treatment, delivery of service, existence of common regulations). However, further opportunities exist also for agricultural and industrial waste water, as demonstrated by the projects described below.

In this section, it will be discussed how more significant opportunities reside in a completely different approach to the way water is selected, and therefore sourced, and used. A shift towards a **fit for purpose approach to water selection** rather than specification of provenance allows **the selection of sources of water alternative to mains water** and opens up the opportunity for **exploiting closed loops or cascading loops of water use**, which extend the use phase of the water itself with tailored treatment. The fit for purpose principle inspired Project Ô (Horizon 2020, Grant Agreement nr. 776816), which is described throughout this section. These loops can be established internally to a single establishment but could also intersect different actors close by, in a territorial symbiosis at district level involving citizens and businesses.

BOX 4 Examples of Horizon 2020 projects focusing on industrial waste water and opportunities for industrial symbiosis

Project WATER2RETURN – "REcovery and REcycling of nutrients TURNing wasteWATER into added-value products for a circular economy in agriculture" (Horizon 2020, Grant Agreement nr. 730398) supports the recovery of nutrients (a nitrates and phosphates concentrate, hydrolysed sludge and algal biomass) from waste waters issued from the meat processing industry for use in agriculture as fertilisers and bio-stimulants. The approach is similar to that of SMARTPlant project, i.e., a reassessment of the functionality of an (industrial) waste water treatment plant to transform it into a biorefinery. Current treatment technologies are complemented by innovative processes that enhance the recovery of value from waste water.

Project ZEROBRINE - "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" (Horizon 2020, Grant Agreement nr. 730390) is a SPIRE project (see section 4.2.2) that aims to prove the recovery of calcium, magnesium and clean water from brines deriving from industrial processes for use by other industries. The target waste water, with a high salt content, is of high interest being a common by-product of desalination/demineralisation of water but also of many industrial processes such as textile dyeing, silica production, coal mining. A complex suite of technologies allowed for a >90% reduction in brine discharge in the environment, while recovering chemicals destined to further purification and use by other sectors or recovered in a closed loop within the same establishment. The project contributes to the new strategic research and innovation agenda

(A.SPIRE, 2021) of the A.SPIRE- EU partnership for the period 2021-2027 "Process4Planet", which aims to zero waste water production by the sectors.

2.4.1 Water (re)use in civil and industrial sectors: some considerations on infrastructure

Water reuse in agriculture is being already regulated (see below section 2.3.1), and an opening is made within the regulatory instruments for water reuse in other applications. However, there are a few real and perceived barriers to be tackled and a need to rethink some of the current approaches to water management before water reuse – and a better use of water - can be implemented in other sectors, particularly in industry and non-food, low-risk civil applications (e.g., road cleaning, irrigation of green spaces but also toilet flushing). Continuing the thread of the parallelism with waste management and recovery, industrial applications represent, from a technical point of view, high-value uses and also opportunities for confinement/concentration of high value compounds or high-risk contaminants. Non-food, low risk applications might have a lower economic impact and might be considered low-specifications, but can use significant quantities of water.

One of the first barrier – but also an opportunity – for water reuse /better use of water in the above-mentioned applications is the current set up of the treatment and distribution infrastructure, which serves civil and many industrial users, particularly SMEs operating in urbanised areas. Our water system is geared up mainly for servicing the civil uses of water and treatment of civil waste water. Main features of this treatment and distribution infrastructure are:

- water treated to drinking quality standards,
- large volumes of water moved from and to large treatment plants,
- microbiological treatment of (human) sewage as standard technology for waste water processing.

This infrastructure guarantees access to safe water and sanitation to millions of people in the developed countries and it has been built during the centuries, expanding as required with the growth of towns and cities. Broadly speaking, industry takes advantage of this easy and often heavily subsidised system. Water in comes from the mains and it is discharged in the sewage system in the linear fashion under scrutiny. This approach can be a barrier to a better use of water in industry for the following reasons:

WATER IN: For larger and specific industries, there might be some opportunities for abstracting water directly from the environment and using it with limited pretreatment – for example, power stations might use water from nearby rivers or canals for cooling purposes. However, for most factories, mains water might be the only source of water for whatever their processing needs; besides, it is the most convenient: general purpose, ready at the turn of a tap, treated elsewhere. However, with the exception of a few sectors (e.g., food processing, cosmetics), for most industrial applications mains water is **overengineered**.

DISTRIBUTION INFRASTRUCTURE: centralised plants undertake the treatment of drinking water and of used water. They collect and treat large volumes of water that it is pumped out to the users (drinking water) or comes in through large sewage pipes. The installation and maintenance of this underground infrastructure is very costly, and becomes more so as the infrastructure ages. Drinking water leakages from the system are a common problem to many utilities, for whom often the loss of "product" is less economically costly than any repair intervention. Sewage tunnels are costly to instal also because of the earthworks, and therefore lengthy disruptions and effort. A doubling of the infrastructure on a large scale to serve industrial users with non-potable water is not possible and it might not be cost effective, while **small loops of water management** might be possible, with suitable distribution infrastructure that, with shorter lengths and lower volumes, might be less expensive to install and to maintain.

WATER OUT: The civil waste water treatment plants were not originally conceived to receive industrial waters, but alternative infrastructure would not be cost effective considering the variety of industrial water discharges. So, in the common approach, industries might be required to pre-treat their effluents to meet certain emissions limits. Pre-treated industrial waters are then discharged in the sewers. As a result, residues from industrial processes get diluted in the main stream of civil waters, and therefore recovery becomes inefficient. Furthermore, there is a risk that the pretreatment might not work, resulting in untreated industrial waters entering the sewers and therefore the civil waste water treatment plant, causing in some cases issues to the working of the plant itself and often ending up with industrial residues not getting treated and entering the natural water system.

This was the case of the Almendralejo case study within Project Ô: local food processing industries (mostly olive preserves /olive oils, releasing polyphenols, brines etc.) would discharge pre-treated process waters in the sewer. Occasionally, spills of untreated water would reach the local civil waste water treatment plant affecting the microbiological treatment, as the water released contain compounds toxic to its biota. The company would get fined but the system would need restarting, at a cost, while in the meantime waste water would get sub- standard treatment and get released to the environment (in this case the Guadiana River). This is an issue common to many waste water treatment plants, where the microbiological treatment might get inhibited by toxic compounds brought about by industrial waters (Yua, et al., 2022). The approach proposed by Project Ô was that of devising a monitoring system able to detect such spills and trigger a deviation of the flow of waste water towards a mobile plant able to deal with the toxic compounds. The monitoring system would be based on an innovative smart biosensor detecting changes in the quality of sewage water sampled. The biosensor is constituted by a selected bacteria strain, which would react quickly to toxic waste water so to enable a fast response of the flow control. The toxic water would be deviated towards a mobile plant carrying photo Fenton technology. This is an Advanced Oxidation Processes (AOP) generating radicals able to oxidise the strong chemical bounds of organic compounds, reducing therefore their toxicity. Because of its higher relative cost with respect to the microbiological treatment (Yua, et al., 2022), this type of process is only deployed when required and on limited quantities of water. This flexibility of treatment could be implemented because of the in-line monitoring and its fast response, a major improvement on the common practice of lab analysis of water samples, with results obtained with a time lag exceeding the window of opportunity for intervening to divert the flow. Furthermore, the plant configuration warrants the opportunity to move it to a different position (e.g., tertiary/polishing treatment) or to shut it down quickly during low season. Furthermore, the mobile plant could foster a different approach and an underlying change in the relationship between the waste water treatment plant (and the community and environment it serves and protect) and the polluters, enacting the "polluter pays" principle, or a new service model: as soon as a "toxic water" spill is detected, the mobile plant is deployed at the source of the pollution with the polluter paying for the operation of the plant rather than the fines.

2.4.2 Water (re)use in civil and industrial sectors – a shift in the approach: specified provenance vs fit for purpose

In the urbanised and industrialised areas, utilities deliver water to both civil and industrial users. Unless large quantities are required e.g., for cooling (power stations) or energy production (hydroelectric) or for specific uses (production of foodstuff, cosmetics, pharmaceuticals), industry and SMEs in particular use water sourced from and as delivered by the mains, i.e., water treated to drinking water standards. This happens whatever the application: heat exchange circuits, plants washing, products rinsing etc. The availability and suitability of mains water for those applications is guaranteed by the source, i.e., the tap. In almost all cases, water from the mains is cheap; furthermore, water from the tap is in endless supply as industrial users exploit the utilities' obligation to provide drinking water to the citizens, the main water users for the service. The provenance of the water – the mains - is implicitly specified and never questioned.

However, many applications do not require water as microbiologically pure and with low chemical contamination as per Drinking Water Directive standards.

BOX 5 The Drinking Water Directive

Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption (the Drinking Water Directive, (Council of the European Union, 1998)), applies to all distribution systems serving at least 50 people or distributing at least 10m^3 per day (and those below such parameters if part of an economic activity), water for drinking issued from tankers, in bottles or containers and water used in the food processing industry. The Directive had been amended during the years, with the recast and revised Drinking Water Directive adopted in December 2020, in force since January 2021 and to be implemented by the MS into national law before January 2023.

The Directive aims to protect human health by ensuring the water intended for human consumption is free from microorganism and parasites and from any other substance which are dangerous to human health. Therefore, it sets down the MINIMUM requirements that water should meet for being considered safe for human consumption. The 2020 recast considered the results of a European citizens initiative (the "Right2Water" initiative), which noticed, amongst other issues, the lower reliance on the risk-based approach introduced with the 2015 Council Directive amending Directive 98/83/EC (European Commission, 2015). It was recognised that the risk-based approach should apply to the whole (drinking) water cycle, from abstraction and treatment to storage and distribution, and should include a reduction at source of the pollution so to reduce the level (and therefore the energy and overall cost and effort) of treatment required (Council of the European Union, 2020). The 2020 Council Position focuses on quality without considering quantitative aspects, in line with a common approach by the water policy up to the year 2022 (see below chapter 3) although it does mention that MS should take into account the effects of climate change on water resources. Such effects should be taken into account in a risk assessment of the water bodies used for abstraction, but no further specific instructions are given.

Often companies do not know what characteristics should have the water used for their application. To fill this knowledge gap, the International Standard Organisation has been working on specifications for the reuse of water (ISO 20670 – Water Reuse – Terminology) (ISO, 2020) in industrial applications, starting with industrial cooling systems (ISO, 2020). ISO 22449-1 "Use of reclaimed water in industrial cooling systems – Technical Guidance" provides typical quality water specifications for make-up water (i.e., water added to a system to compensate for water losses through evaporation, leakages, purges etc) to be used in cooling systems. **Cooling circuits** are used for cooling of products, mechanisms and machinery in a variety of industries – materials working (e.g., welding equipment, rolling mills, presses, extruders, injection moulding etc), lasers processing, chemical processing (e.g., jacketed reactors), medical equipment etc. In this application, water flows in a system of pipes/tanks, which are in contact with the parts requiring cooling (usually water does not enter in contact with the hot parts directly); water is used to remove heat and transfer it to air using often a simple heat exchange process. In their simpler form, these circuits use water from the taps and for larger quantities and complex systems, have a water tower. After cooling the target plant/process, water might be discarded or, more commonly, it is recirculated. A storage and pumping system therefore might be in place[4]. The main specification for the incoming water is linked to its temperature, which is clearly required to be lower than the temperature of the piece of equipment requiring cooling down. A constant or at least regular flow is required for effective heat exchange, with an increase in the flow of water the typical strategy for increasing heat exchange, at least for applications where no strict temperature control of the process or the equipment is required. This might be the case for example for cooling of plant parts to limit their distortion under high temperatures. The water inside the chilling circuit is not accessible to operators, hence the requirements on microbiological purity are much slacker than those for drinking water. They might be set by the need to control fouling of the system, which in turn would determine lower flow rates and losses of cooling performance. Depending on the circuit (e.g., width of the pipes, materials used), some requirements might be set on water hardness and content of salts (alkalinity), to limit corrosion and scaling. Furthermore, especially in recirculating systems, some chemicals to control fouling might be added as the warm temperatures favours bacterial growth.

This application is therefore ideal for the adoption of alternative sources of water, that could be checked or treated for achieving the overall requirements described above. The table below shows the comparison between the requirements of standard ISO 22449-1 with those of the Drinking Water Directive and those of Regulation 2020/741. Tap (drinking) water is clearly overengineered with respect to the requirements, while treated urban waste water meeting the requirements of Regulation 2020/741 (European Parliament and the Council, 2020), analysed in more detail in section 3.3.3, could be used previous some treatment.

[4] Industrial chillers – closed loop circuits with a refrigeration system to control the temperature of the water issued – might be used for a better control of the cooling process. They typically used deionised water for best control of heat exchange characteristics; however, their operating cost (electricity for the refrigeration cycle) might be significant. They are therefore adopted only for very critical processes or for significant cooling requirements.

Table 2 Comparison of specification of water for cooling with specifications from Water Reuse Regulations and from the Drinking Water Directive

Quality requirements	**ISO 22449-1:2020**	**Water reuse regulations (Reg 2020/741) – Class B water**	**Class C water**	**Drinking Water Directive**
E. coli (number/100 ml)	≤200 (fecal coliform	≤100	≤1000	0
BOD_5 (mg/l)	≤10	*25 mg/l O_2		NA
TSS (mg/l)	≤10	*35-60		NA (acceptable turbidity)
Other	Not specified	Legionella spp.: < 1 000 cfu/l where there is a risk of aerosol		*Clostridium perfringens* including spores 0 nr/100ml
Intestinal enterococci (number/100ml)	Not specified	Not specified		0
pH	6,5-9	Not specified		6,5 - 9,5
Total hardness (CaCO3mg/l)	≤250	Not specified		To be indicated but not prescribed
Alkalinity (CaCO3mg/l)	100-500	Not specified		Not specified
COD_{cr} (mg/l)	≤30	*125mg/l O_2		
TDS (mg/l)	≤5000	Not specified		
Conductivity (µS/cm)	≤3000	Not specified		2500
Residual Chlorine (mg/l)	End 0,1~0,2	Not specified		
Chloride (mg/l)	≤300 (stainless steel) ≤1000 (other metals	Not specified		250
NH_3-N (mg/l)	≤5 ≤1 (if copper present)	*(10-15 total Nitrogen)		0,50

	ISO 22449-1:2020	Water reuse regulations (Reg 2020/741) –	Drinking Water Directive
Sulfate (SO_4^{2-}) (mg/l)	≤800	Not specified	250
Fe (mg/l)	≤0,3	Not specified	0,2
PO_4^{3-} (mg/l)	≤3	*(1-2 total phosphorous)	NA

**From Urban Waste Water Directive*

It is recognised that standardisation overall plays a significant role in enabling innovation also in the adoption of circular economy approaches, by filling regulatory gaps and supporting companies looking for a proven, industry-wide level of best practice beyond just the few case studies shown through research and innovation projects. It is however interesting to notice that the approach followed by the ISO 22449-1 is **performance-based rather than recipe-based**, and therefore identifies and expresses in measurable parameters the requirements of the application rather than relying simply on tradition. As a consequence, water sources can be evaluated for their characteristics rather than their provenance, and different options (mains water, reclaimed water with or without further treatment) can be compared against an objective set of engineering requirements. Once the performance requirements have been evaluated or achieved, comparison can be made on economic opportunity, considering e.g., costs, liability and impact. Until mains water is sufficiently cheap and treatment technologies might be complex, water from the tap is likely to remain the preferred choice. Water from the mains is a convenient raw material, and industry has no economic or political drivers for a change in supply. These conditions constitute a major barrier towards adoption of alternative sources of water. However, as enterprises start to become more aware of the need to use resources more wisely and embrace the green transition and its reporting, they can approach water-smart choices with appropriate selection tools.

BOX 6 Alternative sources of water: the case of the Puglia region for the delivery of drinking water within Project Ô and project WATER-MINING

Horizon 2020 Project Ô – "Demonstration of planning and technology tools for a circular, integrated and symbiotic use of water" demonstrated, amongst other approaches, how alternative sources of water could also be used for drinking supply. This is a case demonstrated in Puglia, Italy. Drinking water is brought to Puglia from the reservoirs in Basilicata and Campania as the Region has virtually no sources of freshwater and, before the construction of the ducts, rainwater collected in tanks was used traditionally for drinking. The region is characterised by carsism (karst); hence all water accumulates underground. Around 200 artesian wells are also available to satisfy local needs for drinking water, however many present issues because of water contamination from land use and sea water infiltration caused by abstraction for irrigation (Puglia has a flourishing agricultural sector). Project Ô proposes a small-scale treatment unit able to deal with both salinity and chemical contamination whilst delivering abatement of microbiological content through the ADV.ERT module. This is a containerised system comprising of an ultrafiltration unit for brine retention and an innovative pulsed electric field technology, an advanced oxidation process dealing with persistent organic contaminants and microbial contamination. The small scale and compactness of the unit means that it can be easily used locally, e.g., to supplement drinking water from the aqueduct, and can also be deployed in emergency situations.

Project WATER- MINING – "Next Generation Smart Water Management Systems" (Horizon 2020 Grant Agreement nr. 869474) explores different water sources (sea water, urban water and industrial water) for maximising recovery of freshwater, nutrients and chemicals. Fit for purpose water and zero liquid discharge feature amongst the water services being developed by this project which has reached is second year in October 2022. Desalination operated by renewable energy sources with recovery of salts from the brine is the main technology for freshwater production, while energy efficiency of nutrients recovery from waste water is also being explored amongst other technologies.

2.4.3 Closed loops and cascading loops of water use: the Project Ô approach

Water exiting industrial establishments might be subject to some pretreatment to meet certain quality requirements (i.e., emission limits) before discharge in the civil sewers or, less commonly, directly in the environment. This to avoid pollutants from industrial processes entering the waste water flow and, potentially, affecting the biota of the waste water treatment plant or not being captured before re-entering the natural water system. In these cases, industry is already equipped with some form of (partial) waste water treatment systems, tailored in volumes and technology to the specificities of the discharge (i.e., waste water composition). This established approach could be further exploited, reproducing the concept of value recovery that is being explored for civil waste water treatment plants (see section 2.3.2): water can be recovered for reuse within the same plant it originates from; substances recovered might be of use for the same process (e.g., catalysts) or recovered for use by other markets. The treatment would still need to deal with pollutants, according to the use specifications for the reclaimed water. This **closed loop** approach has the advantage that the industrial user of the reclaimed water knows exactly where it comes from; it can control its quality and would only pay for any top up water and for disposal services for a reduced quantity of waste water (assuming the water could not be cycled forever). For the waste water service provider, reduced industrial water quantity translates into lower risk and reduced treatment flows, while the liability for the pollutant removal still remains with the waste water producer. This approach has been experimented within Horizon 2020 Project Ô for the recovery of water issued from a textile company in Omis, Croatia. The company needed to improve its existing waste water treatment plant and was interested in reducing its water footprint. The opportunity arose to propose a system and a suite of technologies for the treatment of certain flows of waste water to make it available for reuse. The reclaimed waste water would still contain a certain quantity of salts used as catalysts in the dyeing process and otherwise lost with the water sent to disposal. By adding freshwater to the reclaimed water obtained through nanofiltration and/or photocatalytic treatment, the resulting water would reach the required specifications for use in fabric bleaching or washing.

The closed loop approach is also conducive of recovery of substances from waste water, which can be used internally, to generate new business or to support existing local activities. This is demonstrated by the Project Ô demonstrator of Eilat, Israel, located at the National Centre for Mariculture. This research centre is experimenting inland aquaculture of seawater fish. Water from the fish tanks is already recirculated after treatment; however, part of it is disposed of in the sea. Current treatment deals with organic waste and ammonia, which is converted to nitrates. However, other pollutants cannot be treated and nitrates themselves risk to accumulate in the tanks; furthermore, much more stringent regulations forbid discharge of nitrates-contaminated water in the sea, because of their eutrophication potential. Finally, fish waste contains phosphates and other organic matter, which could be used as fertiliser by nearby farming communities. Project Ô delivered a composite module able to improve water treatment reaching high percentages of recirculation through:

- An algae unit, which exploits the "waste" water for producing biomaterial that can be used for feeding the fish themselves, or for production of cosmetics, biofuel and fertilisers
- An activated carbon adsorption unit that separates nutrient rich water from clean water delivered back to the fish tanks.
- The nutrient rich side stream is further treated to reduce salinity and deliver water useable for salt resistant crops, which are therefore fertigated.

This demonstrator embodies the circular economy paradigm of water as it achieves minimisation of water use through full closed loop recovery of water and nutrients from used water also regenerating the local environment whilst supporting food production and new business opportunities.

2.5 CONCLUSIONS

The circular economy framework applies to the whole water management system, not just to waste water. However, a few changes in approaches are required:

- Risk- based approach allows to use reclaimed water from treated waste water safely, and it includes an implicit acknowledgement that the treatment of waste water can vary according to the risk to human health deriving from the use of such water in agriculture;
- This approach extends to a fit-for-purpose application of water, whereby the use of water defines the chemical, physical and microbiological characteristics of the water itself;
- For many applications, drinking-standards water is over engineered and many other sources of water could be explored and ad hoc treatments to obtain the required water characteristics;
- Amongst the many sources of water, reclaimed water looped in the same process (close loop), or waste water from nearby users (cascading loops) could be considered. This would also allow for direct recovery of water enriched with useable compounds while keeping the water in use.
- Waste water treatment plants should become recovery facilities/biorefineries where all elements composing the "waste" water are recovered, beyond treated water and sludges and exploiting symbiotic relations with industry and successful public-private partnerships.

Research and innovation projects supported by the EU framework programme H2020 demonstrate that the above approaches can be implemented successfully. Furthermore, standardisation bodies are actively discussing water reuse and issuing documents to provide engineering guidance for industrial applications.

Many challenges remain open, from the scaling up of innovative technologies supporting full recovery of value from "waste" water to infrastructure supporting water symbiosis. A review of the results of the projects financed within Horizon 2020 is provided in Annex I.

3 EU POLICY AND REGULATIONS ON WATER AND ON CIRCULAR ECONOMY: STARTING POINTS, CONVERGENCES AND OPPORTUNITIES

3.1 INTRODUCTION

The European activity on water regulation and policing started in the 70s. Traditionally, water policy at European level has mostly focused on water quality to ensure protection of the environment and human health. Quantitative aspects, in particular practical ways to address water scarcity or to regulate amount of water used, have been addressed implicitly as linked to the need to ensure the achievement of good ecological status and/or ecological flow of river basins. Water quantity is an issue clearly within the remit of the Union' policy on environmental matters, that, according to Article 191 of the Treaty of the Functioning of the European Union (TFEU) (Consolidated version of the Treaty on the Functioning of the European Union, 2016), shall contribute to "prudent and rational utilisation of natural resources and [...] to combating climate change". Furthermore, Article 192 of the TFEU gives the European Council the power to adopt measures affecting, amongst others, "quantitative management of water resources or affecting, directly or indirectly, the availability of those resources", with the Member States allowed to maintain or introduce more stringent regulations (Article 193 of the TFEU). Water is a very complex area of policy, which interfaces with land use, biodiversity and soil, human health and wellbeing. Socioeconomic impacts of water policy are very high. In this document, however, only aspects linked to the "material" circularity of water as a resource have been analysed in depth.

Section 3.2 analyses water policy and regulatory instruments at EU level focusing on the developments that lead to the latest regulations and the upcoming reviews of existing directives, and on the uptake of water quantitative policy in the last ten years. Section 3.3 considers the evolution of water policy as it is aligning with circular economy policy. The Chapter concludes with the latest developments as at October 2022 and a look forward towards possible future policy actions.

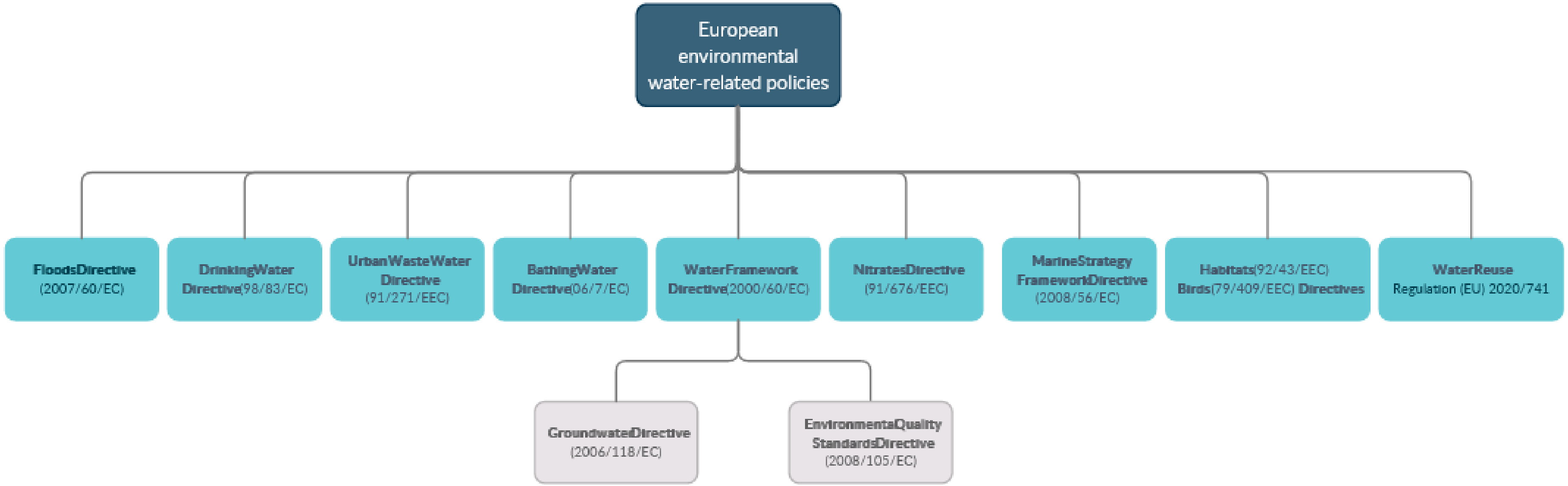

Figure 4: Overview of the European Water related policies, taken from https://water.europa.eu/freshwater/policy-and-reporting/environmental-policies

3.2 EU WATER LEGISLATION UP TO 2022

3.2.1 From first generation water policy to the Water Framework Directive

The EU has been legislating on water since the 70s, generating a patchwork of regulations and directives which have concentrated, with mixed results, mostly on the **quality** of European waters (European Environmental Bureau (EEB), 2005).

The first generation of water policy and regulatory instruments were issued in the early 70s with the First (1973–1976) and the Second (1977–1981) Environment Action Programme, the strategy guiding the progress of the EU environmental policy and the integration of the environment into other policy areas. The Second EAP in particular advocated quality values for water (Giakoumis, 2018). This first wave of Directives, developed as independent and parallel rather than integrated (Academy of European Law (ERA), not available), included the following:

- Bathing Waters - Council Directive 76/160/EEC (Council of the European Union, 1975)
- Dangerous Chemicals - Council Directive 76/464/EEC (Council of the European Union, 1976)
- Fish Waters Directive - Council Directive 78/659/EEC (Council of the European Union, 1978)
- Shellfish Waters Directive - Council Directive 79/923/EEC (Council of the European Union, 1979)
- Groundwater - Council Directive 80/68/EEC (Council of the European Union, 1979) and
- Drinking Water - Council Directive 80/778/EEC (Concil of the European Union, 1980).

Those first directives approached **water <u>quality</u> standards** (Kaika, 2003). Most of the above pieces of legislation have been superseded as they presented implementation challenges (European Environmental Bureau (EEB), 2005) and had been criticised for having a limited approach, as they did not address directly the sources of the pollution. Furthermore, they focused mainly on a single specific target (public health) for the water service, lacking a comprehensive approach with respect to the resource water and its many uses (Giakoumis, 2018).

During the '90s, water legislation addressed the sources of the pollution, and took the approach of controlling **emission levels** as a means of achieving the desired standards. This second period of activity expressed:

- the Urban Waste water Treatment Directive - Council Directive 91/271/EEC, (Council of the European Union, 1991)
- the Nitrates Directive - Council Directive 91/676/EEC, (Council of the European Union, 1991),
- many 'daughter directives' implementing the Dangerous Substances Directive (Council of the European Union, 1976) and
- a revised Drinking Water Quality Directive – Council Directive 98/83/EC (Council of the European Union, 1998).

Important developments of the environmental policy of the period include the issue of the Integrated Pollution and Prevention Control Directive – Council Directive 96/61/EC (Council of the European Union, 1996), one of the expressions of the Fifth EAP (1993- 2000), which had as a main priority "integrated pollution control as an important part of the move towards a more sustainable balance between human activity and socioeconomic development, on the one hand, and the resources and regenerative capacity of nature, on the other" (Council of the European Union, 1996). The same EAP called for a proposal for a directive concerning improvement of the ecological quality of surface waters, which was issued in 1994 with COM (93) 680, the proposal for a Directive on the Ecological Quality of Water (European Commission, 1994), which can be considered the first partial embodiment of the current Water Framework Directive. This draft Directive proposed a '*framework for MS to improve the ecological quality of all surface waters by taking measures to control pollution from point and diffuse sources, as well as other anthropogenic factors affecting water quality so as to maintain and improve the ecological quality of Community surface waters with the ultimate aim of achieving good ecological quality*' (European Commission, 1994). "Ecological quality" is determined by some parameters such as dissolved oxygen, concentration of toxic substances, health and diversity of fauna and flora, status of the coastal and riparian areas etc. "Good ecological quality" is defined in a qualitative fashion, comparing the above parameters to those of a similar water body not significantly affected by human activity and/or taking the survival and reproduction of indigenous animals/aquatic species as the evidence that toxic substances or dissolved oxygen are at an "acceptable" level of concentration which also does not prevent "normal use" of such water body. Quantitative aspects enter as a consequence of the achievement of "good quality status" of surface waters, and in terms of **increased availability of resources for producing water suitable for drinking, agricultural, industrial and recreational use and other uses essential for human and economic activity**. This a rather unidirectional view of water usage. Furthermore, "increased availability" due to good ecological status is to be quantified as '*savings in treatment expenses for this water as a result of implementation of the proposal*'. The proposal was to establish a procedural framework rather than a set of prescriptions and to combine the two main approaches adopted so far in water policing, i.e., emission level control and quality standards. As further developments in policy making at international level, including the United Nations Rio Conference in 1992, introduced the concepts of integrated river basin management, these were included with the above and generated the first proposal for the Water Framework Directive, i.e., COM/97/0049 (European Commission, 17), then transformed, after hard negotiations, in the current Water Framework Directive.

The Water Framework Directive (European Parliament and Council of the European Union, 2000)) has the objective of defining a framework for the protection of waters (inland, transitional, coastal and ground) so to preserve and enhance the status of aquatic ecosystems. It is a complex piece of legislation aimed at organising the body of regulations on water developed up to then. Its key characteristics reside in:

- the identification of the river basins as the unit for water management, beyond and across regional and national boundaries;
- the objective of achieving good quality status for all waters, applying ecological protection to all waters and specific protection of unique habitats, drinking water resources and bathing water as applicable in each river basin;
- the integration of the management of surface and groundwater. For the former, good ecological status is to be achieved, defined in terms of the quality of the biological community, the hydrological characteristics and the chemical characteristics. For the latter, it is the chemical quality that needs to be preserved. The biological quality depends on the local conditions, and it is considered good if it approaches the status of minimum impact from anthropogenic impact; chemical status for surface waters is instead defined through limits of concentration of pollutants. For groundwater, chemical purity is assumed as discharges in ground water are prohibited. Groundwater must be monitored for pesticides, biocides and nitrates, which might reach the aquifers through the soil and its uses (e.g., agriculture), and for changes in chemical quality. The latter could be a consequence of anthropogenic pressures, which must be limited.
- the definition of the maximum quantity of water that can be abstracted by a groundwater source, recognising the significant time required for natural aquifer recharge and the need for maintaining the system of water bodies supported by such source
- the definition of a mechanism for a regular review of the types and limits of pollutants to be checked in surface waters to ensure good chemical status)
- the coordination with other measures, for example the Nitrates Directive (Council of the European Union, 1991), the Industrial Emissions Directive (European Parliament and the Council of the European Union, 2010) etc.
- the use of pricing as an incentive to sustainable use of water resources.

Implementation of the Water Framework Directive is being closely monitored, with the Member States finding many difficulties in its implementation. According to the 2019 monitoring report (European Commission, 2019), the Directive's main objective of achieving, by 2015, good status for the over 111 000 surface waters (e.g., rivers, lakes, coastal waters) and the over 13 000 groundwaters in EU territory, has not been reached and the target year has been postponed to

2027. However, this is still considered a very challenging deadline, as at 2019, less than half of surface water bodies had achieved good status. Better results had been achieved for groundwater bodies with overall better trends in a few quality elements and substances.

It can be said that up to and including the Water Framework Directive, the main scope of EU water regulatory activity had been water QUALITY, with the need to explicit policies on water QUANTITY being brought about mostly by parallel developments on water scarcity and drought policing. Reasoning also on water quantity at policy level is a required step to ensure water as a resource is considered in a circular economy perspective.

3.2.2 Policy on water quantity: water scarcity

Water scarcity is defined as "water demand exceeding the water resources exploitable under sustainable conditions" (European Commission, 2007). After the (first) heatwave of the year 2003, which resulted in widespread droughts (defined as "temporary decrease in water availability due for instance to rainfall deficiency") and the recognition that the number of people and the extent of European territories affected by water scarcity was on the rise, the Commission urged the Council and the Parliament to start addressing the issue. COM(2007) 414 (European Commission, 2007), which followed the first monitoring of the implementation of the WFD (Commission of the European Communities, 2007), referred for the first time to a **water hierarchy** (see BOX 7 below) to be followed for mitigating water scarcity. Water hierarchy is therein implicitly defined as measures to be explored before considering the development of further infrastructures for water and a priority amongst competing demand. The preferred mitigation measures include water saving and water efficiency measures, water pricing policy and alternative solutions, although these are not specified in details, while public consumption is to be prioritised above all other demands for use.

After five years, COM (2012) 672 (European Commission, 2012) reviewed progress of water scarcity policy in the years from COM (2007) 414 and analysed if and how water scarcity and droughts, i.e., quantitative aspects of water policing, had been included in the first round of river basin management plans (RBMPs), introduced by the Water Framework Directive, across Europe. The conclusion was rather alarming, as only a minority of River Basin Management Plans analysed water pressure by different sectors or devised water availability scenarios, and in general data on water quantity had not been sought, been available or assessed for reliability. COM(2012) 672 recognises that water quantity policy had been only implicit in the Water Framework Directive, but that River Basin Management Plans required additional tools to implement it, from targets for water efficiency to definition of ecological flows of each river (amount of water required for the aquatic ecosystem to continue to thrive and provide the services relied upon by the many "users", (European Environmental Agency, 2012)) and economic incentives for efficient water use. The conclusion was however that the subsequent implementation cycle of the Water Framework Directive should need to have a stronger focus on water quantity and be accompanied by integration of the same issue into parallel sectoral policies.

COM (2012) 672 fed, amongst other reports and impact studies, into the Blue Print for Safeguarding European Waters (European Commission, 2012), which is the first strategic document calling explicitly upon a stronger focus on water quantity in the policy making and recognising the link between water efficiency measures and the overall resource-efficiency objectives of Europe 2020. To that effect, it pledged to introduce water accounting and water efficiency targets at sectoral level (agriculture, industry, distribution networks, buildings and energy production). The Blue Print touched upon the issue of water metering and water pricing as measures to implement the polluter pays principle and finally recognised the potential of water re-use for irrigation and industrial purposes as an alternative water source.

BOX 7 Water hierarchy

A water hierarchy is provided within COM2007(414) (European Commission, 2007) which acknowledged the increasing risk of water scarcity (water demand exceeding water resources exploitable under sustainable conditions) and the need to move towards a water-efficient and water-saving economy. Therein, water hierarchy is defined as:

- Water saving: improve water (management) efficiency to reduce losses; integrate water-related concerns into water-related sectoral policies to avoid negative effects on water use and inadequate allocations of water amongst economic sectors; finance water efficiency measures; foster the development of water-efficiency technologies and practices
- Water pricing policy: consistently apply the “user pay” principle; put in place water tariffs on the basis of economic assessment of water uses and water value, ensuring different water uses contribute to the recovery of the costs of water services; foster a water saving couture among consumers, requiring low “embedded water” services and goods
- Alternative solutions: desalination, waste water reuse
- Additional water infrastructures: storage of surface or ground waters, water transfers, or use of alternative sources.

3.3 INTEGRATION OF CIRCULAR ECONOMY IN WATER POLICY

3.3.1 Introduction

The policy mainstreaming of the circular economy approach through the Action Plan for the Circular Economy (European Commission, 2015) and the New Action Plan for the Circular Economy (European Commission, 2020)) is being acquired by the water policy making. The first area of intervention that can be clearly marked as influenced by the Circular Economy policy is that of the management of waste water, starting with its reuse. Some further movements towards an overall resource recovery approach in the management of waste water are also visible through high level reports, research and innovation and the re-assessment of existing Directives and Regulations for their relation with Circular Economy policy.

3.3.2 Waste water reuse: policy drivers

While waste water reuse (also called water recycling) had been initially identified mostly as a mitigation measure for water scarcity, a further push towards adoption of EU-wide measures for water recycling came from the policy mainstreaming of the CE approach through the Action Plan for the Circular Economy (European Commission, 2015) and the New Action Plan for the CE (European Commission, 2020)). For what concerns the water policy acquis, waste water reuse is mentioned once in Art.12.1 of the Urban Waste water Treatment Directive (91/271/EEC16), which encourages treated waste water reuse "whenever appropriate"[5]. Later on, in the Water Directive Framework (Directive 2000/60/EC), "efficiency and reuse measures, inter alia, promotion of water-efficient technologies in industry and water-saving irrigation techniques" are mentioned amongst the "non-exclusive list of supplementary measures which Member States within each river basin district may choose to adopt as part of the programme of measures required under Article 11(4)" of the Directive itself. Indeed, (planned) waste water reuse, mainly in irrigated agriculture, has been common practice in many countries globally including Southern Europe, with Member States developing their own set of requirements to regulate such use (Drewes, Hübner, Zhiteneva, & Karakurt, 2017). However, no common, EU-wide standards or approaches had been developed up to then. Waste water re-use was identified in the Blue Print (European Commission, 2012) - owing to stakeholders' pressure – as one of the measures to be implemented within the European water scarcity and droughts policy. It was also considered by the Fitness Check of EU Freshwater Policy (European Commission, 2012) as one of the alternative water supply options. The Commission considered waste water reuse as a valid and lower environmental impact alternative to desalination or

[5] The Urban Waste Water Directive is currently undertaking a review, which is likely to extended the provisions of the new Directive to enhance its circular economy potential particularly in waste water and sludge reuse or recovery (European Commission, 2019) (see BOX 1).

water transfers, provided that a correct instrument was put in place to ensure the safeguard of human health and the environment.

With respect to Circular Economy policing, the Circular Economy Action Plan and the New Circular Economy Action Plan call for water reuse, proposing:

- the former (2015), dedicated legislation setting minimum requirements for reused water for agricultural irrigation and the integration of water reuse practices into water planning and management (Guidelines on Integrating Water Reuse into Water Planning and Management in the context of the WFD, 2016);
- the latter (2020), while acknowledging the potential of the water reuse regulations (European Parliament and the Council, 2020), including also a pledge by the Commission to "facilitate water reuse and efficiency, including in industrial processes" and to "develop an Integrated Nutrient Management Plan, with a view to ensuring more sustainable application of nutrients and stimulating the markets for recovered nutrients". Nature based solutions such as algae are also mentioned as a method for nutrient removal.

The policy instrument called upon the Blueprint 2012 (European Commission, 2012), on waste water reuse was developed during the period 2012 to 2018 and resulted in the Regulation on minimum requirements for water reuse for agricultural irrigation (European Parliament and the Council, 2020), which might be considered amongst the first pieces of water policy where (waste) water (re)use is seen in the perspective of the circular economy. Water reuse and efficiency in industry and integrated nutrient management plans have been analysed before (see sections 2.3 and 0).

3.3.3 Waste water reuse in agriculture and Regulation 2020/741

Waste water treatment plant (WWTP) and other effluents ending up in rivers often makes up a significant fraction of the ecological river flow, especially during droughts and/or seasons of high demand for irrigation (Drewes, Hübner, Zhiteneva, & Karakurt, 2017). The degree of impact in some river basins taken as exemplar within the above-mentioned report could reach up to 82% in some areas of Spain and 68% along some rivers in northern Italy. With such high influx, the dilution potential of "pristine" surface waters is therefore very limited and results in a de facto waste water reuse by users downstream of the WWTP, particularly for agricultural irrigation.

On the other hand, direct waste water reuse in agriculture has been common practice in many southern Europe countries, the ones most relying in irrigation for their agriculture, which have issued national regulations for the use of waste water in agriculture, e.g.: in Italy, the Ministerial Decree DM 185/2003 (Ministero dell'ambiente e della tutela del territorio, 2003), in Spain, Royal Decree 1620/2007 (Ministerio de la Presidencia, 2007) etc. These instruments contained

specifications for water to be used for irrigation purposes, to ensure good production and low contamination.

Waters for irrigation should meet specific characteristics to ensure good quality and quantity of produce (Ayers & Westcot, 1984), such as:

- Salinity (salt concentration at crop roots reduces yield);
- Specific ion concentration (taken up by the plants cause toxicity problems and at high concentrations reduce yield and damages crops);
- Excessive nutrient concentration (causes unwanted vegetative growth and delays in the maturity of crops).

Salinity and the ratio between sodium vs calcium and magnesium content have also an influence on soil structure and ability of the water to reach the roots.

Additional requirements derive from the need to ensure the **safety of crops for consumption or contact**, i.e., no contamination by pathogens or toxic compounds. The risks associated with using water from WWTP is considered high as the Urban Waste Water Directive (Council of the European Union, 1991) does not require disinfection of waters prior to issuing from the plants. With respect to unplanned use of waste waters from rivers, limits imposed by, for example, the Bathing Water Directive (Council of the European Union, 1975) are too slack for limiting risks associated with consumption of products irrigated with waste water. National specifications for waste water reuse in agriculture, following the EU Commission "Guidance document on addressing microbiological risks in fresh fruits and vegetables at primary production through good hygiene" (European Commission, 2017), require strict limits on microbiological threshold values of faecal contaminants and monitoring frequencies, suggesting a **risk-based approach.** To meet such requirements, WWTP need to add tertiary/disinfection treatment.

Regulation 2020/741 on minimum requirements for water reuse for agricultural irrigation (European Parliament and the Council, 2020) recognises that urban development and agriculture put pressure on the availability of freshwater, leading to water scarcity and deterioration in water quality, although this aspect is not the main concern of this piece of legislation, which is mostly concerned with water quantity- a step change in the body of EU legislation. The Regulation addresses one of the alternative water supply methods mentioned within the previous water legislation, i.e., treated waste water issued from a WWTP, for a specific sector, agriculture, recognised as the most water intensive economic activity, introducing minimum requirements that ensure preservation of the highest hygiene standards for food and avoidance of potential obstacles to the free movement of agricultural produce irrigated with treated waste water. The Regulations also recognises that treated waste water carries nutrients (nitrogen, potassium, phosphorus; the latter is also in the list of critical raw materials (European Commission, 2020)) that could be beneficial for the soil hence its application could in part substitute the use of fertilizers (fertigation), although it does not regulate such aspect except for a warning on limiting nitrogen concentration to meet the requirements of the Nitrates Directive (European Council, 1991).

Only waste water issued from a WWTP, i.e., urban waste water covered by Directive 91/271/EEC, the Urban Waste water Treatment Directive (Council of the European Union, 1991) is considered. This is defined as domestic waste water or as a mixture of domestic waste water, run-off rain water and industrial waste water from specific sectors, listed in Annex III of the 91/271/EEC Directive. These are selected food processing industries plus plants manufacturing feed from plant products and treating hides, skins and bones to manufacture gelatine and glue. Industrial waters from other sectors are excluded on the ground of variability of quality (Alcalde-Sanz & Gawlik, 2017) hence polluting potential.

The Regulation approaches the reuse of treated waste water on the basis of a **risk management framework**, following the recommendations by the World Health Organisation (Alcalde-Sanz & Gawlik, 2017) specifying also monitoring requirements. Key to the Regulation is the identification of four different classes of water quality – according to pathogen and microbial content, from lowest (A) to highest (D) -and how such water can be used to irrigate different crops.

Class A water has the most stringent requirements in terms of pathogen contents, biochemical oxygen demand (BOD) and total suspended solids (TTS) and is the only that can be used to irrigate crops that:

- enter in contact with treated water whatever the irrigation technology and
- are to be eaten raw (that would include for example many vegetables including roots and low hanging fruits such as strawberries, tomatoes, etc).

Classes B and C are used for crops not directly in contact with water or not eaten raw and are suitable respectively for all types of irrigation and for drip irrigation only. Class D is used for crops not destined to human consumptions, hence fodder, fibres, crops for biofuel or other industrial crops.

Treated water must be monitored regularly (Class A must be tested once a week for requirements on E. coli, BOD and TSS; and continuously for turbidity; the other classes with increasing lower frequency) and a clear risk management plan must be in place. International guidance from ISO and WHO is suggested for the establishment of the plan. The plan should also set out measures to avoid contamination of water sources used for the production of drinking water. The Regulations apply to water issued at the point of compliance, i.e., the WWTP, while for the end user (primary agricultural production) continue to apply the EU food and feed hygiene legislation and related guidance documents.

The Guidelines to Regulation 2020/741 (European Commission, 2022) specify that water reuse may be completely or partially banned by Member States. This needs to be justified to the Commission, and can be motivated by availability of other sources of water or by the need to ensure minimum ecological flow for specific river basins when water issued by WWTPs is quantitatively significant and diversion for agricultural irrigation would compromise other uses of the water from the river and its overall status. However, bans can also be imposed on the grounds of high cost of the required polishing treatment, bearing in mind the cost- benefits assessment should consider also environmental costs and costs and consequences of abstraction from other sources. The Guidelines also expand on the risk assessment required by Regulation 2020/741. In particular, it considers chemical contamination of the reclaimed water, providing reference to all other Directives that apply to water issued by a WWTP reaching the environment and water bodies destined to bathing or as source for drinking water or groundwater, as illustrated in Figure 5:

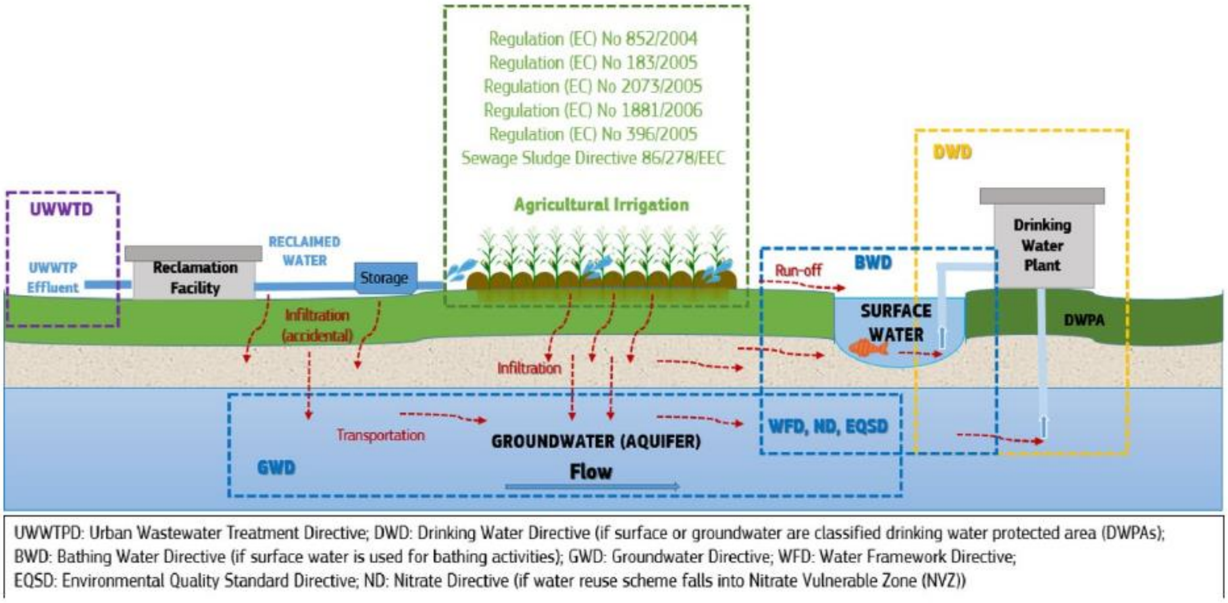

Figure 5 Example of (i) how to identify applicable directives and regulations in a water reuse system, based on potential pathways taken by reclaimed water to the surrounding environments (surface water and groundwater) and (ii) regulations and directives that could apply to agricultural irrigation, depending on specific agricultural practices (European Commission, 2022)

Taking a risk-based approach, it is considered that, in general, chemical contaminants are present in low concentration in waters issued from a WWTP and therefore they pose a low risk to human health. However, accumulation in the environment should be prevented, and specific measures should be adopted to limit known pollutants (e.g., from local industries discharging in the sewage system reaching the relevant WWTP), according to the standards set at national level by the River Basin Management Plans, where River basin Specific Pollutants might be identified.

The waste water reuse for agriculture regulatory approach provides an example of specification-driven water treatment that could be extended to other uses of alternative water sources. The characteristics required by the application (limits on certain physicochemical properties for ensuring soil and crops health; acceptable contamination) are clear. Furthermore, the risk-based approach allows for a modulation of such specifications, which have an impact on the type of treatment for (waste) water destined to such applications, and consequently, on its cost. Indeed, the Regulation specifies that the reclamation facility must set out to treat water issued by the WWTP to achieve a certain water quality for a specific use. Reclamation facility operators are responsible for the quality of the water issued at the point of compliance, i.e., where the water produced is delivered to the next actor in the supply chain. **This specification (or performance) driven approach has an important role in supporting a circular use of water resources,** as discussed in section 0**.**

The application of these regulations at EU level could lead to water reuse in agricultural irrigation in the magnitude of 6.6 billion m3 per year, as compared to 1.7 billion m^3 per year in the absence of any EU legal framework. Re-using more than 50% of the total water volume theoretically available for irrigation from WWTPs in the EU would avoid more than 5% of direct abstraction from water bodies and groundwater, resulting in a more than 5% reduction of water stress overall (European Commission, 2018).

3.4 RECENT AND UPCOMING REVIEWS OF WATER POLICY UNDER THE LENS OF CIRCULAR ECONOMY POLICY

The launch of the Green Deal overarching strategy (European Commission, 2019) and of the many strategic documents stemming from it, including the Action Plans on Circular Economy (European Commission, 2015) and (European Commission, 2020), is intersecting the Fitness Check of the water policy which was undertaken in 2019 (European Commission, 2019). This review highlighted, amongst other areas of improvement, the integration of water into other policies, but did not mention expressly circular economy, while it analysed interaction with energy, soil and agricultural policy and with specific water-related directives such as the Urban waste Water Directive and the Sewage Sludge Directive.

The Urban Waste Water Directive had been subject to a Refit evaluation (European Commission, 2019) which highlighted the positive impact of the Directive but also the need to align it with the Green Deals strategy and to better implement the "polluter pays" principle, alongside an update of emission limits. From the Refit evaluation, the EU published many implementing strategies and action plans including the Zero Pollution Action Plan (European Commission, 2021), the New Circular Economy Action Plan (European Commission, 2020), the Chemicals Strategy for Sustainability (European Commission, 2020), the Pharmaceutical Strategy (European Commission, 2020), the Biodiversity Strategy (European Commission, 2020), the EU

Soil Strategy (European Commission, 2021) and the revision of the Renewable Energy Directive (European Commission, 2021) and the recent Repower EU Communication (European Commission, 2022). The Proposal for a revised Urban Waste Water Directive (European Commission, 2022) incorporates as preferred options, amongst other measures:

- integrated water management plans for areas at higher risk, where also preventive measures to limit pollution from storm runoff can be introduced, and these might include nature-based solutions;
- more stringent limit values to nitrogen and phosphorous concentration in treated waters issued from plants;
- new limit values on micropollutants and a system to implement producer responsibility for the additional treatment required to reach such limits;
- better measures to monitor and track non-domestic sources of pollution to favour reclaimed water and sludge reuse;
- energy audits to ensure achievement of energy neutrality, hence favouring production of biogas from waste water treatment.

Many of these measures are to be implemented initially in the largest plants (above 100,000 population equivalent) and then to be extended in time to smaller plants (above 10,000 population equivalent).

The option of imposing EU-wide resource efficiency objectives such as minimum percentages of sludge use in agriculture, minimum levels of recovery of phosphorous and other materials such as cellulose from waste water and sludge, or mandatory anaerobic digestion with linked targets for renewable energy production was rejected as well as the option of introducing minimum rates of water reuse. The opinion of the business stakeholders weighted heavily on those rejections, on the basis of the high variability of plants and local situation (European Commission, 2022).

The Sewage Sludge Directive (Council of the European Communities, 1986) has been evaluated in 2019 (European Commission, 2019), with a Roadmap published for feedback in 2020 and a Public Consultation with selected stakeholders closed at the beginning of 2021. No results have been published to date (due Spring 2022, but not available as yet) regarding the two consultations, however some of the responses provided by water stakeholders have been reported in chapter 4.

3.5 R&I PROJECT RESULTS ADVOCATING WATER POLICY REVIEW

Many of the H2020 projects working on circular economy of water have identified opportunities for its implementation and demonstrated approaches, solutions, technologies and business cases for many of its aspects. A summary of the different projects analysed for this work is reported in Annex I (chapter 6). A few have also highlighted policy barriers and opportunities.

Since 2019, projects developing circular economy solutions for water have had the opportunity to share their findings and work with the EU Commission and Agencies towards policy implementation of project results (e.g., workshop of March 2021 (European Commission, 2021)). A few projects have also developed policy recommendations, such as project NextGen (see BOX 8).

BOX 8 Project NEXTGEN

Project NextGen – "Towards a next generation of water systems and services for the circular economy" (Horizon 2020, Grant Agreement nr. 776541) has had the main objective of furthering the understanding of approaches and technologies supporting circular economy of water, and implemented, to this end, ten large scale demonstrators throughout Europe. Water reuse and management, energy and materials recovery were explored in this four years project concluding in November 2022. The project championed the fit-for-purpose approach and, amongst its results, it developed also a knowledge and exchange platform focused around circular economy achievements (technologies, products, case studies…) covering the nexus of Water, Energy, and Materials – an online match-making marketplace, now hosted by Water Europe, and being further developed with the support of projects B-WaterSmart – "Accelerating Water Smartness in Coastal Europe" (Horizon2020, Grant Agreement 869171) and ULTIMATE – "indUstry water-utiLiTy symbIosis for a sMarter wATer society" (Horizon 2020, Grant Agreement 869318).

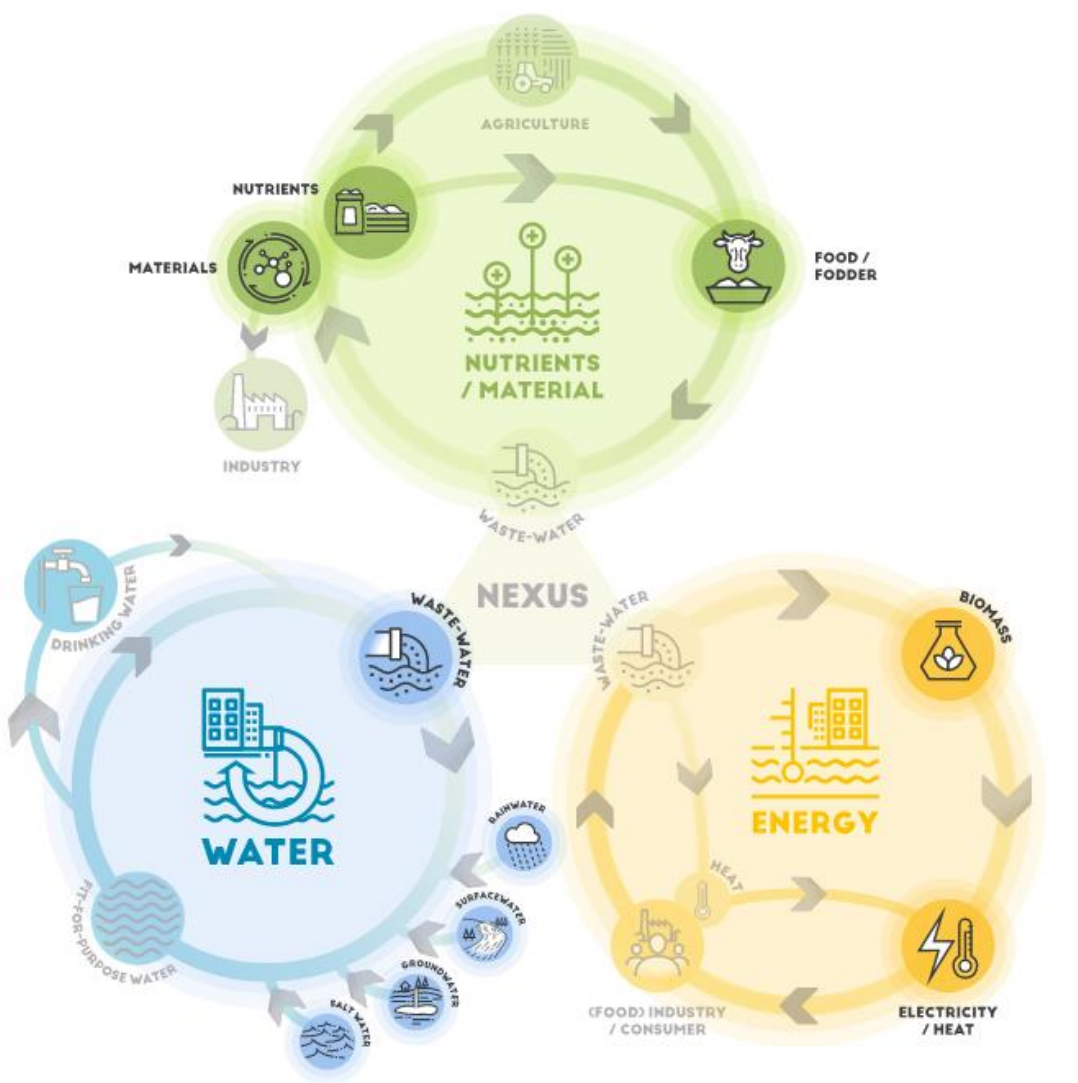

Figure 6 Areas covered by the Marketplace developed within NextGen project

The policy brief developed (NextGen, 2022) includes the following recommendations for the two Directives on waste water:

- Ensure alignment of policy instruments to cover coherently circular economy and introduce measures to incentivise its take up. This to avoid confusion amongst the practitioners, due to contrasting requirements of the many regulations affecting implementation of circular economy approaches;
- Ensure energy efficiency and renewable energy policies include also the water and waste water sector, supporting better performance of water treatments (and therefore innovation) and exploitation of opportunities for biogas generation at waste water treatment plants;
- Introduce the water fir for purpose approach, discussed already in section 2.4.2;

- Recovered products: introduce reporting requirements, facilitate the achievement of and support EU-wide End of Waste status recognition to ensure recovered products can be marketed;
- Support digitalisation to improve monitoring and reporting, tackling also pollutants of emerging concern;
- Support financial incentives for utilities investing in circular solutions and innovation.

3.6 CONCLUSIONS

EU water policy is a complex body of Directives and Regulations that developed since the 1970s and culminated in the Water Framework Directive of the year 2000. The main objective of this policy area is the protection of the environment and human health in terms of avoiding the pollution of water bodies and aquifers and ensuring the quality of drinking water. The management of water is seen mainly from the perspective of the biological side of the water cycle with achievement of good ecological status of river basins through control of effluents discharged into the environment and set limits of pollutant concentrations. Quantitative aspects of water management enter into consideration as heavily influencing the minimum ecological flow of rivers (from what good ecological status also depends). Water scarcity is an issue recognised at EU level but only implicitly included in the acquis of water regulation, as a responsibility of River Basin Management Plans authorities who should identify the pressures on the catchment areas from different users. On the other hand, a few Southern Europe Member States heavily relying on irrigated agriculture have acted on supporting the sector through regulating the use of reclaimed waste water for crop irrigation. This led to the EU Regulations on water reuse, which establish a risk-based approach for the use of treated waste water issued from civil waste water treatment plants for agriculture, with quality of reclaimed water variable as a function of the types of crops to be irrigated. This piece of legislation can be said to be the first implementation of circular economy of water at political level.

With the introduction of circular economy in the EU Policy in 2015 and then the launch of the overall Green Deal strategy, which includes also the New Circular Economy Action Plan and other strategic documents on agriculture, biodiversity, energy, chemicals and pollution, the water policy body is being reviewed and slowly updated. The first area of intervention is linked to waste water, with the evaluation of the Urban Waste Water Treatment Directive and of the Sewage Directive, which include an assessment of their alignment to other EU Policy. The first result of such evaluation is a proposed recast of the UWWT Directive, which intervenes on nutrients content of treated waste water but does not push forward requirements on resource recovery. However, some opportunities open up as the plants are required to draw up integrated water management plans, which might leave space for water utilities and their stakeholders to implement technologies and approaches to maximise value recovery from waste water (water, nutrients, energy). R&I projects around water in the circular economy are demonstrating approaches and solutions that could be used to support a change in policy making. The main conclusion is that the water policy acquis, starting from the Directives most relevant to waste water, needs to be better aligned with the Green Deal, intersecting also policies on energy, food production, biodiversity but also waste and green finance. This is an issue somewhat already identified for materials within the Circular Economy Action Plans; however, for water policy alignment the main challenges might reside in ensuing coherence between the regulation of the biological cycle of the circular economy butterfly (Ellen MacArthur Foundation, 2019) and regulation of the technological cycle, also considering the role of water as interface between the two systems.

4 COOPERATION BETWEEN THE EU AND INDUSTRIAL STAKEHOLDERS IN DEFINING APPROACHES TO A CIRCULAR ECONOMY FOR WATER

4.1 EU INDUSTRIAL STRATEGY

The EU launched COM (2020) 102 "A new industrial strategy for Europe" in March 2020 (European Commission, 2020). The strategy focuses on the twin transition (green and digital) to ensure Europe remains competitive and strategically autonomous. This was accompanied by a specific strategy for SMEs (COM (2020) 103 "An SMEs strategy for a sustainable and digital Europe", (European Commission, 2020)).

Water is not explicitly mentioned in the Industrial strategy, but it is somewhat implicit in a call towards a greener and more circular industry. Specific sectors – steel, cement, chemicals, construction products and built environment, mobility – are mentioned with regards to actions required for emission reductions, while for circularity, the strategy recalls the sectors already mentioned within the New Circular Economy Action Plan (electronics, batteries, textiles). The SMEs strategy is cross sectoral and, with respect to environmental impact and green transition, mentions both the opportunities for SMEs delivering green products and services and also support given by the EU through the Clusters and the European Cluster Cooperation Platform, the European Enterprise Network and the European Resource Efficiency Knowledge Centre (EREK), which specifically provides guidance to SMEs on how to save energy, material and water costs through good practice examples and case studies.

Part of the Industrial Strategies mentioned above are the Industrial Alliances, which currently include the European Raw Materials Alliance, the European Clean Hydrogen Alliance, the European Battery Alliance, the Circular Plastics Alliance amongst others. These alliances are initiated by the EU onto specific value chains to ensure buy in by all stakeholders (industry, EU countries, Regions, financial institutions, civil society, trade unions, academy and research institutions etc) and work with the EU for implementing specific policy objectives. Alliances are not involved in policy making by definition nor they receive direct funding. Current alliances cover supply chains relevant for the Circular Economy Action Plan, such as batteries, raw materials, circular plastics, but none have a specific focus on [circular economy of] water. An Alliance on water would be extremely cross-sectorial and probably unmanageable; however, if the proposal for the introduction of the polluter pays principle in the revised Urban Waste Water Directive was to pass, producers of medicinal and cosmetic products could become one of the first target sectors to be involved in an Alliance on their pollutants.

4.2 PUBLIC PRIVATE PARTNERSHIPS INVOLVING THE EU

The work of the EU with industry on water may be captured within the activities of the many public private partnerships (PPPs) built by the EU Commission and/or Member States during the years, and still active, and linked to research and innovation activities.

Although a few of them touch upon issues linked to water, only the following are analysed in depth to capture if and how water is considered in the context of the circular economy and what is the industry buy-in in delivering solutions supporting this approach:

- WATER4All (co-funded PPPs), which draws mainly from the Water JPI (Joint Programming Initiative, a Public-to-Public partnership);
- Processes4Planet (co-programmed partnership), which is the successor of the Sustainable Process Industries through Resource and Energy Efficiency (SPIRE) cPPP, involving A.SPIRE, the Association of Sustainable Process Industries through Resource and Energy Efficiency.
- CBE (Circular Bio-based Europe) Joint Undertaking (JU), which is the successor of the "Bio Based Industry" Joint Undertaking – BBI JU bio-based industries, which involves the Bio-based industry Consortium – BIC;
- Built4People (co-programmed partnership), which is the successor of the Energy-efficient Building (EeB) contractual PPP (cPPP), which involves the European Construction, built environment and energy efficient building Technology Platform (ECTP);
- Made In Europe (co-programmed partnership), which is the successor of the Factories of The Future (FoF) cPPP, involving EFFRA, the European Factories of the Future Research Association.

4.2.1 Co-funded, Article 185 and institutionalised PPPs: WATER4All

This partnership has been co-funded by the EU through Horizon Europe and aims at "enabling water security for all in the long term through boosting systemic transformations and changes across the entire research – water innovation pipeline, fostering the matchmaking between problem owners and solution providers" (WATER4All, s.d.). The partnership includes representatives from 31 European and non-EU countries and it groups policy makers, local authorities and water thematic authorities, research organisations, R&I funders, networks and associations representing the water value chain. These include: Water JPI, EurAqua, EurEau, Aqua Publica Europea, Water Europe, European Water Association. It started its activities in June 2022 and it is managed by the French Agence Nationale de la Recherche. Some of the members of this partnership are reference stakeholders for water policy, and their vision with respect to water will be analysed in section 4.3.

WATER4All deals mainly with freshwater security challenges, from source to sea for urban and rural areas. Water for circular economy features as the first of its seven themes within its draft Strategic Research and Innovation Agenda (SRIA) and the implementation of a water-circular EU economy is amongst its expected impacts (WATER4All, 2021).

Figure 7 Depiction of the seven themes of the WATER4All SRIA, from https://water4all-partnership.eu/

The Water for Circular Economy theme is subdivided in three sub-themes, each with a list of related topics, as reported below, with some commentary.

Table 3 Sub-themes of the WATER4All R&I "Water for Circular Economy" theme "

Sub-theme	**Related Topic**	**Comments**
I.I. Water supplies for socio- economic development and activities, such as agricultural, aquaculture, urban, industrial and energy uses.	Developing innovative water allocation policies and management practices.	Both these topics are strictly related to water QUANTITY and address the theme of increased water scarcity. These are particularly relevant to water planners and could fit with the River Basin Management Approaches required by the Water Framework Directive, as improved with the findings of the Water Blueprint.
	Developing a new water demand management approach including long-term water demand forecasting and scenarios.	
	Developing smart water use and efficient technologies for irrigation and industrial purposes	One of the few technology-related topics within this theme, looking at innovation towards optimisation of the water usage in agriculture and industry (reduction of water quantities required).
	Mitigating impacts from energy and raw materials production.	Link with the water-energy nexus (e.g., water demand for hydroelectric vs ecological flows in times of droughts; water as heat carrier and impacts on ecosystems) and with pollution from raw materials extraction
	Developing and testing scalable and affordable solutions to allow the prioritisation of investment and activities for climate change resilience	This topic links with the impacts of climate change on water, from droughts to floods, and again is relevant from a planning and policy point of view.
I.II. Circular economy.	Developing circular economy approaches to urban and industrial waste water treatment plants.	This topic links with the view also brought about by a few research projects (e.g., SMARTPLANT, Project Ô) and the recent review by the EEA on sewage treatment (European Environment Agency, 2022), i.e., maximising value recovery from (waste) water. This is another topic where technological innovation and innovative business models need to be developed – see also below.

Sub-theme	Related Topic	Comments
	Water –Energy – Food – Ecosystems (WEFE) Nexus: - Assess the interlinkages and interdependencies of water, food and energy sectors and ecosystems in a context of climate change in different water bodies, in particular transboundary ones (from monitoring schemes, demand forecasting, socio-economic assessments, scenario planning, behavioural change, cost-benefit analysis), to implement a real water-energy-food nexus approach and increase efficiencies, equity and sustainability. - Advancing a holistic approach in the WEFE Nexus through the inclusion of health (One Health concept). - Identifying and investigating drivers, pathways, nature and types of barriers of the Nexus	This nexus and/or the bilateral nexus are key to ensure the appropriate exchange of nutrients, allocation and use of water resources, preservation of ecological flows. The nexus becomes more and more relevant as water scarcity affects an increasing number of areas. This is an area of highly political relevance and potential conflict as sufficient water is prerequisite for the survival of the economies.
	Developing and implementing the “Fit-for-use” concept for water-dependent sectors.	A fundamental topic for the implementation of the circular economy of water, i.e., optimising water treatment for its use rather than adopting a blanket approach of using mains water, which is often overengineered

Sub-theme	Related Topic	Comments
		for many applications.
	Understanding and quantifying trade-offs between alternative interventions for a better integration in the implementation of interventions.	Cross-boundary policy topic for water resource planners also calling for better instruments in spatial planning.
	Developing and optimizing technologies for the recovery and valorisation of resources (including energy, minerals, metals, salts, nutrients, cellulose) from (waste) water, and the production of novel feedstocks from waste water (e.g., bio-plastics, PHA, natural flocculants, kaumera gum, etc.), brines and sludges.	Linked to the "vision" above regarding a redefinition of (waste)water treatment plants, this topic explicates the need for technological innovation to ensure also recovery of substances carried within used water and novel value chains producing alternative raw materials from them.
	Sustainable sediment recovery and use from reservoirs	Also linked to the water-energy sector for hydroelectric reservoirs.
	Developing innovative traceability systems to guarantee the quality of recovered products and improve confidence of the market.	This topic presents a common issue for secondary raw materials, i.e., building trust in the users by ensuring constant quality they are used to for virgin raw materials.
	Quantifying the long-term implications of water reuse on environmental compartments.	Potential for accumulation of pollutants of emerging concern or other toxic substances still present in water treated for reuse.
	Developing robust methods and indicators	Monitoring of the new approach is required to ensure the solution

Sub-theme	Related Topic	Comments
	for measuring transition to circularity, its benefits, challenges and trade- offs	proposed is an overall improvement.
	Developing new management tools and methodologies, partnerships and business models for industrial processes and agricultural water reuse and recycling. This topic will also look at the development of matchmaking platforms for the valorisation of waste water based on its value for different industries (and sectors), and the implementation of decentralised treatment systems in synergy with existing centralised treatments	Another key factor for the implementation of circular economy for water (but also for other resources) is the requirement for supporting infrastructures and facilities, to implement industrial symbiosis. Producers of used water are best placed for the recovery of valuable substances with ad hoc, localised treatment plants (see section 2.4.3 above).
	Progressing in the understanding of the socioeconomic aspects, governance and behavioural changes for developing social acceptance of reused waste water.	Public perception of water reuse can be a powerful barrier, for example for enabling used water reuse in irrigation of green public spaces or road cleaning, and tools are required to heighten trust in the regulatory approaches taken (i.e., risk-based approach for water reuse in agriculture).
I.III. Empowering the public, water users and stakeholders in valuing water.	Developing a bottom-up approach for co-design and co-construction of solutions for water users.	These topics approach the need for a co-creation approach to support the required changes in policy and implementation of circular economy for water. Indirectly, they also touch upon the issue of water value, although do not refer directly to water pricing, which is highly controversial despite being one of the tools supported by the Water
	Raising public awareness for the value of water and public participation in RDI	

Sub-theme	**Related Topic**	**Comments**
	through the use of water footprint models	Framework Directive.
	Understanding and assessing the values of water for the public and stakeholders to guarantee sustainability of water and limit use conflicts.	
	Developing methodologies to assess stakeholder responsibilities in setting the right prices to reflect the marginal value of water.	
	Developing participatory foresight approaches to raise stakeholders' awareness of the long-term value of water resource protection.	
	Exploring the possible routes to conduct paradigm changes to be innovative for water governance.	

Further links to the Circular Economy theme are included in:

- Theme II: Water for ecosystems and Biodiversity within sub-theme II.I – Functioning and biodiversity (dynamics and functioning of vulnerable water ecosystems of regional interest).
- Theme III: Water for the future: sustainable water management within subthemes:
    - III.I. Integrated Water Resources Management (Developing and demonstrating Integrated management and monitoring of the whole water cycle (including surface water and groundwater interaction, water reuse, storage and managed aquifer recharge) in the framework of the land-water interface.);
    - III.III Groundwater management (Supporting land and aquifer management in inland and coastal aquifers through a better understanding of abstraction and recharge volumes, seawater intrusion and salinization and contamination);
    - III.V Tools for water management, including – amongst others- scenario analysis ("Smartening the water system" for advanced decision support and priority setting, sensor networks, big data, information and control systems for water, network communications, digital twin models, advanced technologies and capabilities for quasi-real time data collection, analysis, modelling, forecasting and visualisation technologies.
- Theme IV: Water and health, within sub-theme IV.III. Innovative water tools and technologies for water quality monitoring and water treatment, remediation and disinfection (Water treatment, remediation and disinfection for drinking water and sanitation, including Developing more efficient, cost-effective, less energy dependant, low carbon footprint and easier-to-implement technological solutions for drinking water and waste water treatment; Developing new process and product controls for small decentralised drinking water treatment systems; Sustainable management and valorisation of residues from desalination plants to protect land, water and sea ecosystems altogether).
- Theme V: Water Infrastructure, within sub-theme V.I. Adaptation of existing water infrastructures to new challenges (New sustainable treatment systems to secure water quality (robustness, security, operable, energy efficiency and chemical consumption, at lower cost)

Many of the topics listed above have already be subject of research and innovation projects within Horizon2020 and it is expected that WATER4All will lobby for ensuring the water issue becomes more prominent also in the Horizon Europe Agenda.

4.2.2 Co-programmed Public Private Partnerships and Joint Undertaking in research and innovation

Within Horizon 2020 and Horizon Europe, the European Commission established some specific PPPs for research and innovation formed by the EU with industrial associations representing specific sectors. These PPPs, a category of the many PPPs formed by the EU during the years, are included in the R&I Framework Programmes (Horizon 2020 and Horizon Europe) to contribute directly by co-defining industrial challenges and by co-investing in R&I in their solutions. In this section are analysed the programmatic documents related to strategic R&I within Horizon 2020 and Horizon Europe of the following cPPPs, to highlight if and how water features within, and if and how circular economy of water is taken into consideration. The reference industrial representation and the reference documents within the two framework programmes are illustrated in Table 4 below.

Table 4 Reference PPPs within Horizon 2020 and Horizon Europe with reference industrial associations

Reference association	Horizon 2020 PPP	Horizon Europe PPP
A.SPIRE	SPIRE cPPP	Process4Planet cPPP
BIC	BBI JU	CBE JU
ECTP	EeB cPPP	Built4People cPPP
EFFRA	FoF cPPP	Made in Europe cPPP

4.2.2.1 A.SPIRE- EU PPPs

A.SPIRE is the European Association representing innovative process industries, bringing together cement, ceramics, chemicals, engineering, minerals and ores, non-ferrous metals, pulp and paper, refining, steel and water sectors. Its mission is to contribute to a resource efficient process industry through the development of enabling technologies and best practices along the value chains.

A.SPIRE entered into the SPIRE cPPP with the EU for Horizon 2020. The SPIRE Roadmap (A.SPIRE, 2013) describes the 2030 vision and the steps required to achieve it. Water sector is included within the scope of the membership and water issues are brought forward in terms of reduction of water usage for achieving the overall aim of 20% reduction in non-renewable, primary raw material intensity, to be calculated through life cycle analysis. Entering the specifics of the key actions (KA) linked to key component of the research and innovation strategy, water features as follows within the Key component: Feed and the KA 1.3: Optimal and integrated (re) use of water. Here considerations are given to the opportunities to reduce use of water and use of chemicals for water treatment, recovery of heat exchange value from hot/cold water streams as a measure to reduce energy consumption for heating and cooling, end-of-pipe (small loops) water treatments to optimise recovery of value from process water streams. Water symbiosis and delivery of fit-for-purpose water are considered as key elements to ensure and enable the optimal and integrated (re)use of water. Water symbiosis is mentioned as a way to keep water in use for example in industrial parks, supported by monitoring systems assessing quality and quantity, and control of impurities in closed water cycles to limit risks for companies choosing to reuse water or use waste water. Integration of water and energy, as ensuring that new water management measures are energy efficient and for the recovery of heat from water is brought forward together with the recognition of the vulnerability of process industry to water scarcity and possible measures to mitigate the risks Throughout the remainder of the Roadmap, water efficiency, reduction of emissions to water, use of waste water as secondary feedstock – often in a close loop, valorisation of sludge from waste water, and technological innovations supporting such measures are mentioned associated to the other 4 components (Process, Materials for resource and energy efficient process, Resource and energy efficient applications). Actions on water were expected to produce the most impact in the short and medium term, as a recognition of the amount and urgency of work required to address the issue.

The 2021-2027 cPPP partnership driven by A.SPIRE is called Process4Planet. Water features even more heavily in its Strategic Research and Innovation Agenda (A.SPIRE, 2021) and it is identified predominantly in the circularity pathway for the delivery of the 2050 process industry, with the ambition to close material loops, from waste to resource and water reuse, through resource and water efficiency and an overhaul of the use of waste and water and the very ambitious target of reaching near-zero water discharge by 2050. The SRIA supports the move towards toxic free materials (European Commission, 2020) and sees the near zero water discharge ambition as a driver to develop innovative technologies to recover products from water streams and enable its cycling. With respect to the water sector, it recognises opportunities for efficiencies in water processing and the need for the waste water plants to transform into water resource recovery facilities, including recovery of water, resources, energy and heat. The SRIA also includes an evaluation of investment needs for bringing to TRL9 the supporting technologies, and a list of first-of-a-kind plants demonstrating innovation in approaches and technologies.

4.2.2.2 BCI-EU PPPs

The Biobased Industry Consortium (BIC) is a non-profit organisation set up in Brussels in 2013 to represent the private bio-based industries sector in Europe a Public-Private Partnership (PPP) with the European Commission. BIC represents sectors such as agriculture and agri-food, aquaculture and marine, chemicals and materials (including bioplastics), forestry, pulp and paper sectors and technology providers and waste management and treatment.

BIC engaged with the EU Commission for the period 2014-2020 in the Horizon 2020 Joint Undertaking known as the Bio-based Industries Joint Undertaking (BBI JU). In its 2013 Strategic Innovation and Research Agenda (Biobased Industries Consortium, 2013) the BBI expresses one of its aims towards accelerating the building of bio-based value chains, starting from sustainable feedstock production and mobilisation towards the implementation and use of bio-based materials and products. Process and waste water are considered amongst the categories of biomass and organic waste inputs to biorefineries for the manufacture of biobased products and their market, which includes biobased chemicals and materials, advanced biofuel, food ingredients and bioenergy. The Agenda addresses also the production of biomass and lignocellulosic materials, featuring concerns on water use efficiency in agriculture through crop rotations and better management (e.g., precision farming, other agronomic solutions). It recognises expressly the fact that waste water is an underused source of biomaterial that could be the basis for new value chains addressing also the increase of waste flows, specifically considering opportunities for recovery of phosphate from some process waste water and for fertigation practices through water reuse. It also pledged to get involved in a (then) candidate European Innovation Partnership on water. The 2016 update of the SIRA (BIC, 2017) specifically mentions sludge from waste water treatment, waste water from agro-food production processes as focus for new bioeconomy value chains based on innovative technologies and cascading and circular approaches. Municipalities, cities and other stakeholders within the waste water area as identified are partners to work with to enable exploitation of that resource. Water reduction is mentioned as one of the challenges for innovative processing and improvement of biomass pre-treatment and conversion. Water reuse in the process is mentioned as one of the objectives of innovative process water treatments dealing with product recovery and contaminants removal to enable closed water loops.

The Horizon Europe BIC-EU Joint undertaking is denominated Circular Bio-based Europe (CBE), bearing in its own name the vision and the alignment with the EU Green Deal. The CBE Strategic Research and Innovation Agenda published in June 2022 (CBE, 2022) reviews the achievements of the BBI in the previous framework programme and sets out to address its shortcoming. While recognising the results of the previous Ju, CBE intends to drive a full circularity of the sector through research and innovation pushing further on conservation of water, preservation of biodiversity in water ecosystems, reduction of nutrients load in waste water, water use reduction, recovery of (value from) waste flows. Its objectives include number 3 "Ensuring environmental sustainability of feedstock" with a KPI (#3.2) on number of projects using feedstock generated with practices aiming at zero-pollution (soil, water, air) and/or at reducing water consumption and a target of 40. It also looks at the potential for using bio-based solutions for monitoring systems/devices of environmental conditions, such as air, water, and soil quality.

4.2.2.3 ECTP- EU PPPs

The European Construction, built environment and energy efficient building Technology Platform (ECTP) was founded in 2004 gathering more than 140 Member organisations from across the construction sector and other sectors from the whole supply chain of the Built Environment. It is one of the 38 European Technology Platforms (ETPs) recognised as stakeholders' forum by the European Commission for the sector. The ECTP operates through a number of committees working on energy efficiency, digitalisation, heritage and regeneration, infrastructure and mobility, materials and sustainability, active ageing and living environment.

Within Horizon2020, ECTP established with the EU the Energy Efficient Buildings cPPP, where water is considered mostly for its relation with energy (heat exchange) and services to users of buildings (sanitary water). Within Horizon Europe, it launched, with the European regional Network of the World Green Buildings Council, the Built4People cPPP. Water enters in the Built4People Strategic Research and Innovation Agenda (Built4People, 2022) mainly connected to the needs for solutions enabling a better integration of buildings to the city networks, in particular water and wastewater, to encourage the local re-use of water and waste heat, as well as an optimised management of wastewater and rainwater (solve sanitary issues, economic competitiveness of solutions, standardisation) into the R&I topic 3 "Smart-grid ready and smart-network ready buildings, acting as active utility nodes in smart communities". Natural based solutions are called upon in R&I topic 9 "New reliable and robust approaches to circular economy (for both technology-based & nature-based solutions)" connected to water systems to be used to mitigate the effect of climate change in cities.

4.2.2.4 EFFRA-EU PPPs

The European Factories of the Future Research Association (EFFRA) is a non-for-profit, industry-driven association promoting the development of new and innovative production technologies. It represents manufacturing industries and it has the key objective of promoting pre-competitive research on production technologies.

EFFRA has engaged with the EU Commission in PPP since Horizon 2020 with the Factories of the Future (FoF) cPPP. In its multi-annual roadmap (European Commission, 2013), water is considered under the heading of the manufacturing challenge of environmental sustainability of manufacturing. While energy efficiency is the predominant preoccupation, reduction of water use (and of "any other material resource that does not end up in the final product, but instead ends up in the form of waste or low value-added by-product") is also considered. Water is not mentioned within the challenge related to the optimisation of materials exploitation in manufacturing processes (challenge 5.4.4 within the roadmap), where use of waste as resource is mentioned, and is referred to in the industrial symbiosis sub challenge (challenge 5.4.5). Innovative enabling technologies are considered key to address the environmental sustainability challenge, however water is not explicitly mentioned as one of the areas where improvements can be achieved. Circular economy does not feature at all in the document, owing to its date of publication (2013) anterior to any EU policy on it. Water and circularity feature however in a document addressing the last Horizon2020 Work programme, "Factories 4.0 and beyond" (EFFRA, 2016) where water is explicitly mentioned in the context of industrial symbiosis, and the challenge of efficient use of water is accompanied by a pledge to lower emissions also to water. Circular economy enters as one of the five key priorities of the FoF 18-19-20 programme as the context for sustainability of value networks., with a recognition that manufacturing drives the circular economy itself. The European Circular Economy Open Platform is been named as one of the focuses to implement this specific vision, with focus on de- and re-manufacturing, energy and materials efficiency, servitisation of products. Water does not enter specifically in this context.

For Horizon Europe, EFFRA engaged with the EU in the Made in Europe cPPP. Its Strategic Research and Innovation Agenda (European Commission and EFFRA, 2021) refers to the four specific objectives of the partnership, which include Specific Objective 1 "Ensuring manufacturing excellence" and Specific Objective 2 "Circular products & Climate-neutral manufacturing". Water is mentioned amongst KPI#3 "Number of demonstrators and actions targeting green and resilient manufacturing (either factory level or entire supply chain)" of the first Specific Objective, with a dedicated target of 50 demonstrators, with 15-30% less water use. Specific Objective 2 has one single KPI, #10 "Number of new circular value chains" with target of 30 cases demonstrating new innovative circular value chains. In this document water is therefore explicitly considered as a resource whose consumption must become more efficient, through reduction of water needs. Circularity of water is not explored specifically.

4.3 OTHER WATER STAKEHOLDERS AND THEIR VIEW ON CIRCULAR ECONOMY OF WATER: WATER EUROPE

Water Europe was initiated by the European Commission (EC) in 2004 as the European Technology Platform (ETP) for water with the name WssTP. This ETP status was renewed by the EC in 2013 in line with its ETP2020 strategy. Water Europe is a multi-stakeholder platform of reference representing the whole value-chain of water and aiming to achieve a European Water-Smart Society. Water Europe's Vision, published in 2016 (Water Europe, 2016) identifies the pathways towards better use, valorisation and stewardship of water sources by society and businesses. It also considers resilient and sustainable solutions required to face key global water challenges. It identified a water smart society of the future where "water scarcity and pollution of ground- and surface water in Europe are avoided; water, energy and resource loops are largely closed to foster a circular economy; the water system is resilient against climate change events; and European business dependent on water thrives as a result of forward-looking research and innovation". The paradigm shift envisioned includes "digital water" technologies and increased availability of "multiple waters" to complement freshwater sources, with higher degree of collaboration amongst the water users and stakeholders, including citizens, and a strongly embedded recognition of the true value of water. This is key to ensure water use and reuse are rationalised and implemented, supported by digitalisation of water infrastructure, hybridisation between engineered and natural based water solutions and infrastructure, multistakeholder governance. Circularity of water is brought forward in the technological cycle through cascading, reuse, recycling. The Vision is accompanied by a Strategic Innovation and Research Agenda (WaterEurope, 2016) to implement the steps required to achieve such vision. Water Europe is part of the Water4ALL and the SPIRE PPPs.

4.4 CONCLUSIONS

Water features at the top of the innovation and stakeholders dialogue agenda of the EU who has instituted a specific EIP and ETP. The Water ETP in particular – Water Europe – is bringing forward a water vision that encompasses circularity. Water Europe is very active also in R&I projects and in voicing the views of water stakeholders for policy and political interventions – last one at the time of writing is the European Parliament decision to include the concept of Water-Smart Society in a motion for a resolution on the UN Climate Change Conference 2022 (COP27). The analysis of the main PPPs who have included water as an area of activity within their scope and/or Strategic Research and Innovation Agendas depicts once again the transversality of the issue "water" but also the different take up by the sectors. This specifically highlights the room for improvement in the stakeholders' dialogue, who are approaching in a fragmented way water and, more rarely, water in the context of circular economy. Process industries and biobased industries appear to be the most understanding of the opportunities and needs to drive innovation towards circular water use, while this understanding is lower for manufacturing and for buildings.

5 ANALYSIS OF MAIN RESULTS OF A SELECTION OF RESEARCH AND INNOVATION PROJECTS

Most of the projects mentioned in this review have completed their activities. A selection of the major results in terms of innovations developed is hereby reviewed.

SERIOUS GAMING for CIRCULAR WATER ECONOMY:

Serious Gaming (SG) and System Dynamic Models (SDMs): SG is an approach used to facilitate awareness raising in citizens about complex issues (sustainability, planning options, energy conservation for householders etc) for example by modelling the effects of certain choices on a system, supported SDMs. NEXTGEN developed a digital testbed tracking the flow of water, resource and contaminants within a urban water system, using a mass balance (volumetric) approach. It includes libraries of water use, water reuse and wastewater treatment components that can be tested within this model to maximise the resource potential of the water and material moving through the cycle. On top of this it added layers on materials (chemical composition- resource of pollution); energy (energy demand and production potential linked to the water cycle), environment (environmental flows of surface water, quality of water returned to the environment), and finally a financial layer (costs associated with the treatment of wastewater, cost-benefit potential from reclaimed resources from the treated wastewater). It aims to demonstrate how interactions between water, energy, and materials/embedded resources within the urban water cycle can be utilised in the context of the Circular Economy of water. This SDM supported one of the serious gaming activities of project NEXTGEN, using a testbed/artificial case study (referred to as the "Toy Town"). Other serious gaming activities were based on real case studies developed within the project, i.e., treatment and reuse of wastewater for supplementing demands for golf courses and cleaning streets in Costa Brava (Spain); treated water-reuse, and nutrient and thermal energy recovery for tree nurseries in Athens (Greece). The case studies enable the exploration of novel technologies related to the circular economy of water; in particular, how these technologies may help manage water, energy, and material-based resources more effectively to meet the challenges that future climate scenarios may pose. (Evans, et al., 2023) **Innovation:** the NEXTGEN SDM allowed to insert a whole catalogue of approaches supporting circular economy of water and the WEFE nexus. It filled a gap with respect to SG associated to water, which covered mostly management of water systems, flood and drought prevention, training for emergency response, conflict resolution (Khoury, Evans, Chen, & alii, 2023).

MULTIRESOURCE RECOVERY FROM BIOLOGICAL WASTEWATER TREATMENT PROCESS.

Project SMART-PLANT delivered scaled-up solutions in n.6 existing wastewater treatment plants (WWTPs) with the aim to recover and recycle chemicals and nutrients in an energy- and carbon efficient way. In those Water Resource Recovery Facility (WRRFs), the solutions delivered:

- CaPO4
- Struvite
- more than 400 kg per week of clean cellulose fibres or cellulosic sludge
- more than 1 kg polyhydroxyalkanoates (PHA) per day.

Recovered cellulose, PHA, PHA-rich sludge, CaPO4 and struvite were post-processed to produce bio-composite in an industrial extruder, to produce (after bio-drying process) biomass fuel having 3940 kcal/kg calorific value, and or to be added to mortars to increase lightness, flexural strength and hygrometric properties. Moreover, the agronomic properties of P rich sludge are under investigation in real field for maize growth. The recovery processes were optimised for energy efficiency, resulting in significantly low GHG emissions and started a process of validation under the ETV programme, an EU initiative validating the green claims of new technologies with certification by third parties. **INNOVATION:** resource recovery coupled with water treatment in one step; energy efficient recovery processes. The resources extracted by the SMARTechs (cellulose, nutrients and PHAs) are formed into products. The first technology uses cellulosic and PHA materials to make biocomposite plastic that can be used in the construction industry or for consumer goods. The second one consists of dynamic composting to produce commercial fertiliser or biofuel out of cellulosic and phosphorous-rich sludge.

ON DEMAND TREATMENT

Project Ô experimented a system for automatic evaluation of treatment requirements according to the quality and toxicity of water. It considered the pairing of a standard microbiological treatment with an Advanced Oxidation Process (photocatalysis). The principle behind was an optimisation of cost and efficiency: as biotreatment is more economic than AOP, the integrated system needed to exploit as much as possible the former while reducing the load on the latter and reserving treatment for the compounds most toxic for the bioreactor. Project Ô trialled a unit that monitors in real time the viability of a reporting bacteria; according to the toxicity, the unit controlled a number of operating lamps in the photocatalytic reactor autonomously according to predetermined toxicity setpoint (Yua, et al., 2022). **INNOVATION:** this supports the fit for purpose approach: water is treated according to specification.

NOVEL CIRCULAR MODELS FOR WATER-STRESSED REGIONS: Project HYDROUSA demonstrated small loops of water treatment applying nature based solutions and optimising use of alternative sources of water as well as recovery of energy and nutrients. he model is based on the valorisation of non-conventional water sources to generate water suitable for different uses (irrigation, potable, domestic use) as well as to produce high added value products (agricultural crops, superfoods, edible salt, compost, essential oils) to regenerate the interrelated circular economy loops. The main advantage of the HYDROUSA approach is that all recovered products and resources will be exploited locally for the benefit of local communities and agricultural cooperatives, minimising in this way the long supply chains, the high transportation costs and eliminating externalities. **INNOVATION:** This model strongly supports the concept of social justice and fairness in the utilisation of resources among communities.

6 SUMMARY AND CONCLUSIONS

This work has tackled the research question about how circular economy applies to water, conceptually and practically. It has analysed the concepts, the policies, the industrial and European Commission's research and innovation strategies and activities supporting the implementation of a circular economy of water.

Water is a limited resource, considering the low availability of useable freshwater, its many roles in the natural environment, the anthropogenic direct and indirect pressures – from irrigated, fertilised agriculture to (other) man-made pollution and climate change. The balance of exchanges between the natural and the technological loops of this resource needs to be redressed, with lower abstraction of water from the environment, longer permanence in use within the technological loop through reuse and recycling, regeneration of its pristine quality for the return to the environment. A circular economy perspective applied to water management supports this.

Some actions for implementing this circularity are in place. For instance:

- Circular economy is mainstreamed from a regulatory point of view on "waste" water treatment for the reuse of water in agricultural applications, through Regulation 2020/741. This piece of legislation is the first issue of an expected wave of review of the water regulatory framework under the lens of circular economy and other Green Deal policies and regulations. The Regulation introduces a **specification based approach** in the preparation and use of treated "waste" water in irrigation, which could be adopted for other applications;
- "Waste" water treatment plant role is evolving. Successful demonstrators show that they can be managed as a **biorefinery/resource generation hub** delivering not only treated "waste" water and sludge but also high value organic and inorganic compounds from substances suspended/soluted in "waste" water. Suitable technologies, cooperation links and business models support this evolution for a complete recovery of value from "waste" water;
- Industry and civil sectors are yet to be tackled significantly in terms of introduction of circular economy concepts, although a few demonstrators are showing interesting case studies. One significant exception is an activity at standardisation level to support enterprises in adopting water reuse for cooling circuits, a low-risk application: ISO Standard ISO 22449-1:2020 defines the parameters that "waste" water must meet for

becoming suitable for reuse. This is an example of **specification for use** which provides a clear set of characteristics by which determines which water **whatever its origin** can be used;

- Nature based solutions are being selected by communities and cities as a way to address the water-(energy) -food-environment nexus. Their appeal lays mainly in the many services they offer and in their low cost; furthermore, they are key for the regeneration of water to be sent back to the environment and can provide also social benefits.

Further steps towards a full adoption of the circular economy for water include some changes in approach, and, consequently, regulatory, planning and technology tools and solutions.

In accordance with the overall concept of circular economy, "waste" water does not exist. Already the transformation of "waste" water treatment plants in resources hub is driving this. Pollutants old and new are an issue to be solved at source by avoiding their use. The issue is part of the Green Deal zero pollution ambition and the Chemicals strategy for sustainability, which is fundamental for supporting a complete recovery of "waste" water. The stigma associated with "waste" water will certainly not disappear with a change of definition, however this might reinforce the concept that "waste" water is only water carrying substances to recover or to further treat and one of the many **alternative sources of water** that could be considered and treated according to applications and needs. A **specification-based approach** and the understanding of the **performance requirements** of water in its applications would support this.

Water minimisation, as reduction of water needs by processes and products, is one of the areas less integrated in the current approach of innovation supporting water in the circular economy, as it can be seen by reviewing the H2020 projects related to the water and circular economy topic (Annex I)– only a very few projects have tackled the issue. This is another parallel with resource use. Water footprinting is helping in identifying products and processes with lowest "embedded water", yet there is a need to reconsider industrial activities to support achieving lower scores and supporting technologically and politically the effort.

Keeping the asset water in use for as long as possible is an approach strictly linked to the adoption (and consequent implementation) of the concept of **water fit for purpose**. Once better understood the application and its requirements (the ratio of ISO 22449-1:2020), including those deriving by the need to protect human health and the environment, there is a need to approach the sourcing of water by considering the range of sources available (not just the mains water, but also used water from own processes or from other processes) and the most suitable treatment bringing such water to specification. It is very convenient to use water from the mains – cheap, readily available, responsibility of others – yet this is often **overengineered for many applications**. The access to **alternative sources of water** poses a number of challenges, starting from access: factories might be able to deviate own used waters from discharge to operate high value applications reuse in closed loop, but can hardly source water used by others. On top of the infrastructural and, potentially, permitting aspects, flexible treatment technologies might not be available. This switch can be supported by the introduction of **small loops of water treatment**, which connect locally users of water/ producers of used water (prosumers) and are served by **small scale, smart water treatment plants**. The advantages of small loops reside in the fact that the specific used water of a certain system does not get diluted into the massive flow of civil waters, for example: this can support the recovery of valuable compounds but also a more efficient treatment of pollutants, particularly those not as yet regulated/difficult to treat/present in very small quantities but accumulating in the environment. The disadvantages are clearly linked to the need to invest in an alternative distribution infrastructure, and who would be paying for that.

Finally, technological advancement is required. A few plant-scale demonstrators have performed efficiently for the recovery of resources from used water, transforming the waste water treatment plants in resource recovery hubs. On the opposite scale, nature based solutions have proven key for the implementation of a holistic approach to value recovery from water serving agricultural communities and developing also growth opportunities.

The major area of technological development identifiable is in technologies serving the management of small water cycles. With respect to local treatment plants, cost efficiency could be an issue with smaller scale, however some approaches could help in mitigating this: for example, multipurpose treatment plants with in-line sensors able to analyse the quality of water and a system able to decide the best pathway (most efficient treatment train vs application, or no treatment if cost prohibitive or not required). These plants could be shared by a local community of prosumers, paying for their service.

ANNEX I: HORIZON 2020 PROJECTS DEDICATED TO WATER IN THE CONTEXT OF THE CIRCULAR ECONOMY

Horizon 2020 research and innovation work programmes issued many specific calls on water-related issues, including, but not limited to, water in the context of the circular economy. The calls topics most relevant to circular economy and projects funded are summarised in the following pages and tables. The projects most relevant from a circular economy perspective have been analysed using the CORDIS platform (European Commission, s.d.) and grouped by call in the following table. The projects were funded to develop the following topics:

TOPIC WATER-1a-2014 First application and market replication: the challenge under this topic had been set to "seize new and significant market opportunities by positioning Europe as a global market leader in water related innovative solutions" to support the improvement of the state of water resources (European Commission, 2015). The call acknowledges that the objectives of the WFD to achieve good status by 2015 would be met by only half of European waters by 2015 and that, as a consequence, further action would be needed to improve matters, and this is an opportunity for growth of the water management economic actors. **The perspective of this call was therefore about seizing the business opportunity of the water issue,** focusing on 5 thematic priorities (water reuse and recycling; water and waste water treatment, including recovery of resources; water and energy integration; flood and drought risk management; and the role of ecosystem services in the provision of water related services) and 3 cross-cutting priorities (water governance; decision support systems and monitoring; and financing for innovation) identified by the EIP on Water. Projects funded related to circular economy are listed in the following table starting with W1a.

TOPIC WATER-1b-2014 Demonstration/pilot activities: the main challenge for this topic was the implementation of real -scale demonstrators supporting the take up of solutions to the Water EIP priorities, also supporting the objectives of the SPIRE PPP in terms of minimisation of water use by processing industries and raised awareness about the value of water. Projects funded related to circular economy are listed in the following table starting with W1b.

TOPIC CIRC-01a-2016 Systemic, eco-innovative approaches for the circular economy: large-scale demonstration projects: Design for circular value and supply chains. Large scale demonstration projects, involving organisations also from process and manufacturing industries and SMEs dealing with biotic and/or abiotic resources, testing and showcasing circular economy solutions based on re-design of value and supply chains, taking into account products, production processes, and/or systems, as well as involving final users. The solutions needed to entail the environmentally sustainable recovery, recycling and/or re-use of resources and energy flows, including by cross-sectorial symbiosis, within the overall chain from resources to marketed products.

TOPIC CIRC-02a-2016 Water in the context of the circular economy - Demonstrating the potential of efficient nutrient recovery from water: objective of this topic was the implementation of large-scale demonstration projects to tap the potential of nutrient recovery, whose use is to be encouraged throughout Europe. Projects were expected to cover the whole value chain from recovery of nutrients to their recycling, and to involve recovery technologies implemented in any water sector (i.e., industrial, agriculture, or municipal).

TOPIC SPIRE-01-2016 Systematic approaches for resource-efficient water management systems in process industries Optimisation of the use of water in industry, particularly in SMEs. The projects were required to focus on: 1) Combining existing technologies (e.g. advanced processing, nano-technology and materials) in order to achieve enhanced sustainability in water treatment processes by reducing water use, energy and raw materials consumption and at the same time minimizing waste and/or recovering valuable substances. 2) Selective separation processes in order to be able to treat specific industrial fluxes, also leading to the recovery of valuable substances. 3) Adaptation of current processes or equipment to use alternative water sources. e.g. rainwater, salt or brackish water, cooling water, or Waste Water Treatment Plant (WWTP) effluent. 4) Alternative cooling/heating methods. Reducing the energy levels that are needed for water and steam related production processes; dry cooling technologies; water and energy recovery processes from water vapour. 5) Use of renewable energy, in order to achieve low energy water treatment processes (e.g. photo-degradation of pollutants). 6) Development of closed loop recycling and reuse, involving cascading of processes and industrial water symbiosis. 7) Development of a sustainable strategy for selecting materials and infrastructure for water transport and use, including water storage and treatment.

TOPIC CIRC-02b-2017 Water in the context of the circular economy - Towards the next generation of water systems and services – large scale demonstration projects. The objective of this topic was to demonstrate innovative solutions at a large scale (i.e regions, cities and/or river basins), in line with EIP Water priorities and the objectives of the Water Framework Directive. Proposals would focus on developing the water services of the future, going beyond water supply sustainability addressing the different water value chains. They would integrate, for instance, the management of water resources and the provision of water services, expanding the re-use of treated waste water and the use of desalinated water (where appropriate), ensuring carbon neutral water services, and closing the water cycle by increasing the efficiency of wastewater treatment plants, including the recovery of energy and the re-use of chemicals and nutrients.

TOPIC SC5-4-2019a Building a water-smart economy and society - Symbiosis between industry and water utilities. To satisfy the growing demand for water from various economic activities and increasing stress on natural water sources, there is a need to make available alternative water resources of various qualities and which are appropriate for different functions and multiple users, and to better exploit water resources and all the valuable substances that could be obtained through the wastewater treatment and reuse process. The projects are called to demonstrate the feasibility of a 'water smart' economy and society in which all available water resources, including surface, groundwater, waste water, and process water, are managed in such a way as to avoid water scarcity and pollution, increase resilience to climate change, appropriately manage water-related risks, and ensure that all valuable substances that could be obtained from waste water treatment processes, or are embedded in used water streams, are recovered. Resource- efficient solutions derived from the systemic exploitation of symbiotic inter-linkages between wastewater treatment in industry and by water utilities need to be demonstrated. These might address, for instance, the reuse of treated wastewater, the use of substances or energy derived from wastewater treatment, or might demonstrate the concept of dynamic allocation of the right quality of water for the right purpose, while ensuring health and safety.

TOPIC SC5-4-2019b Building a water-smart economy and society - Large scale applications with multiple water users at various relevant scales In line with the previous subtopic, the actions are expected to test and demonstrate systemic innovation in real life, large scale operational environments and address multiple water users (urban, industrial, rural and agricultural) and various relevant scales (regional/national/international). The objectives of the projects should encompass:

- stimulating efficient and multiple use, recycling and reuse of water; recovery of energy and materials (such as nutrients, minerals, chemicals and metals) from water;
- managing water demand and efficient allocation;
- exploiting alternative water sources;
- prevention of water pollution and degradation of the aquatic environment and soil; and
- cost-effective and smart management of the water system and infrastructure.

Table 5 Review of water-related projects funded by Horizon2020 and covering circular economy aspects of water management

Key: A = ICT, data collection and management; B = Minimisation of water use or water losses; C = Reuse of water; D = Innovative and/or low-cost treatments; E = Nature Based Solutions; F = Recovery and use of recycled materials/energy from waste water; G = Use of other recycled materials

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
W1a: 642494 ECWRTI: ECOLORO Reuse of Waste Water from the Textile Industry (ISPT, 2021)	Electro-coagulation (EC) combined with flotation to remove pollutants, colorants and chemicals from waste water from textile industry. Optimisation of ultrafiltration and reverse osmosis membrane processes downstream.			X	X				Addressing the needs of the textile industry
W1a: 642190 iMETland A new generation of Microbial Electrochemical Wetland for effective decentralized wastewater treatment	A system for waste water treatment of urban waste water suitable for small communities (up to 200 population equivalent), using electroactive bacteria and electroconductive material.	X		X	X	X			Technology suitable for small communities
W1a: 641661 POWERSTEP – Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration	Reduction of energy consumption of a waste water treatment plant with biogas production from anaerobic digestion of sewage sludge, and use in combined heat and power plant.	X					X		Biogas recognition as renewable energy; promote energy neutral or energy positive plants for public financing

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
W1a: 641998 REMEB: Eco-friendly ceramic membrane bioreactor (MBR) based on recycled agricultural and industrial wastes for waste water reuse	Implementation and validation of a low-cost ceramic membrane bioreactor (MBR) in a Waste Water Treatment Plant (WWTP), the study of the impact and replication of the technology for the reuse of the water in regions with water scarcity and the industrial sector				**X**			**X**	Alternative materials to lower the cost of innovation for WWTP
W1b: 689450 AquaNES: Demonstrating synergies in combined natural and engineered processes for water treatment systems	Integration of natural based solutions with engineered solutions for the treatment of waste water, storm water, rain water and surface water				**X**				NBS coupled with technological solutions
W1b 689817 INNOQUA Innovative Ecological on-site Sanitation System for Water and Resource Savings	Promoting sustainable water sanitation technologies for water stressed communities without infrastructure, capable of performing a whole water treatment cycle exploiting purification capacity of earthworms, zooplankton, and alternatively microalgae and sunlight exposure.			**X**		**X**			NBS as a solution alternative to infrastructure

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
W1b 688989 INTEGROIL Demonstration of a Decision Support System for a Novel Integrated Solution aimed at Water Reuse in the Oil & Gas Industry.	Development and demonstration of a robust but flexible integrated solution for treating O&G water flows with variable compositions to different water qualities depending on the final reuse objective.			X	X				Solutions for a water polluting idnustry
W1b 689242 INCOVER Innovative Eco-Technologies for Resource Recovery from Wastewater	Moving waste water treatment plants to bio-product recovery hubs, with production of bioplastics, organic acids and biomethane and recovery of nitrogen, phosphorous and reclaimed water.	X		X	X		X		The project took part in the 2019 IWARR post conference workshop in Venice titled H2020 Water Innovations for sustainable impacts in industries and utilities" (EASME and others, 2019)
W1b 689785 SALTGAE Demonstration project to prove the techno-economic feasibility of using algae to treat saline wastewater from the food industry	Demonstration of innovative, sustainable and efficient solution based on algae for the treatment of high salinity wastewater from the food and drinks industry.				X				NBS for industry

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
W1b 690323 SMART-Plant Scale-up of low-carbon footprint material recovery techniques in existing wastewater treatment plants	Demonstration of recovery opportunities at waste water treatment plant level.	X			X		X	X	The project took part in the 2019 IWARR post conference workshop in Venice titled H2020 Water Innovations for sustainable impacts in industries and utilities" (EASME and others, 2019)
W1b 689239 WADI Water-tightness Airborne Detection Implementation	Development of an airborne water leak detection surveillance service to provide water utilities with adequate information on leaks in water infrastructure outside urban areas	X	X						Implementation of systems for the reduction of water leaks
CSA 641821 WATERINNEU: Applying European market leadership to river basin networks and spreading of innovation on water ICT models, tools and data	Creation of a marketplace to enhance the exploitation of EU funded ICT models, tools, protocols and policy briefs related to water and to establish suitable conditions for new market opportunities based on these offerings.	X			X				Support tool (market place) for the selection of solutions addressing the needs of water stakeholders at river bsin level

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
CIRC-01a-2016 730285 RUN4LIFE RECOVERY AND UTILIZATION OF NUTRIENTS 4 LOW IMPACT FERTILIZER	Strategy for improving nutrient recovery rates and material qualities, based on a decentralised treatment of segregated black water (BW), kitchen waste and grey water combining existing WWT with innovative ultra-low water flushing vacuum toilets for concentrating BW, hyper-thermophilic anaerobic digestion as one-step process for fertilisers production and bio-electrochemical systems for nitrogen recovery. It is foreseen up to 100% nutrient (NPK) recovery (2 and >15 times current P and N recovery rates) and >90% water reuse.		X	X	X	X	X		Strategies adopted for wastewater concentration and reuse of reclaimed water are adequate in terms of reduced water consumption, resulting in a decrease in the total amount paid in water and wastewater treatment bills.

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
CIRC-01a-2016 730390 ZEROBRINE 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	Demonstration of new configurations to recover minerals (including magnesium) and water from saline impaired effluents (brines) generated by process industry, while eliminating wastewater discharge and minimising environmental impact of industrial operations through brines. Large scale demonstration in the Energy Port and Petrochemical cluster of Rotterdam Port, involving local large industries. Included recovery of the waste heat.			X	X		X	X	Support the development and updating of strong and credible BREF documentation with detailed information on different brine concentrates, mineral concentrations, efficiency of processing techniques and environmental and societal impacts. Facilitate communication with National Legislative Helpdesks for brine recovered materials to develop EoW criteria that considers the ZERO BRINE technology, as well as between recovery operators with downstream users of the supply chain for pricing information.

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
CIRC-02a-2016 730398 WATER2RETURN: REcovery and REcycling of nutrients TURNing wasteWATER into added-value products for a circular economy in agriculture	Full-scale demonstration process for integrated nutrients recovery from wastewater from the slaughterhouse industry using biochemical and physical technologies and a positive balance in energy footprint. Production of nitrates and phosphate concentrate available for use as organic fertiliser in agriculture, using an innovative fermentative process designed for sludge valorisation which results in a hydrolysed sludge (with a multiplied Biomethane Potential) and biostimultants products, with low development costs and high added value in plant nutrition and agriculture.			X	X		X		Low risk, high value application of circular economy
SPIRE-01-2016 723702 INSPIREWATER Innovative Solutions in the Process Industry for next generation Resource Efficient Water management	Demonstration of approaches and resource -efficient technologies to reduce water and energy consumption, the use of chemicals and the amount of waste so to increase the efficiency of water and raw materials in the process industry.	X	X	X	X		X		Holistic approach to water management that includes life-cycle thinking, resource efficiency, key performance indicators and new technologies, which the process industry can integrate into existing corporate management structures.

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
SPIRE-01-2016 723729 REWACEM Resource recovery from industrial waste water by cutting edge membrane technologies	Reduction of water use, wastewater production, energy use, valuable metal resource recovery and water footprint by between 30-90% in the metal plating, galvanizing and printed circuit board industry. Adoption of two membrane technologies suitable for the requirements of closed material cycles approaches and recovery concepts in metal processing industry: Diffusion Dialysis (DD) and Membrane Distillation (MD) as an integrated hybrid process		X		X		X		
SPIRE-01-2016 723577 SPOTVIEW Sustainable Processes and Optimized Technologies for Industrially Efficient Water Usage	Demonstration of 14 existing and new technologies, including solid/liquid separation, ultrafiltration, deionization, biological treatment, disinfection and chemical heat pump, in order to optimize the use of natural resources, especially water, in three industrial sectors (Dairy, Pulp and Paper and Steel) contributing to 44% of industrial water usage in EU.		X		X		X		Resource optimization (including water, energy, raw materials and additives) as a key issue to maintain production competitiveness and sustainability

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
CIRC-02b-2017 776541 NEXTGEN Towards a next generation of water systems and services for the circular economy	Innovative and transformational circular economy solutions and systems to underpin the exploitation of techniques and technologies that enhance the ability to recover, refine, reuse, repurpose, capture value from, and extend the use-life of, an ever-increasing range of resources and products in the water sector.	X			X		X		Improve alignment between directives and incentivise circularity; include the water / wastewater sector in energy efficiency and renewable energy strategies, but improve alignment with environmental ambitions; adopt the water fit-for-purpose principle; extensive application of digital solutions to increase reporting, focusing on reporting requirements for recovered products; create simpler and less costly routes to market for recovered resources; support an effective regulation which provides encouraging financial incentives targeted toward water reuse schemes and circular water technologies.
CIRC-02b-2017 776643 HYDROUSA Demonstration of water loops with innovative regenerative business models for the Mediterranean region	Demonstration of innovative, regenerative and circular solutions for (1) nature-based water management of Mediterranean coastal areas, closing water loops; (2) nutrient management, boosting the agricultural and energy profile; and (3) local economies, based on circular value chains. Use of unconventional sources of water including wastewater, rainwater, seawater, groundwater and vapour water.	X	X	X	X	X	X		Natural based solutions for localised treatment and uses of alternative sources of water.

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
CIRC-02b-2017 776816 Project Ô Demonstration of planning and technology tools for a circular, integrated and symbiotic use of water	Approaches and technologies to drive an integrated and symbiotic use of water. Innovative technologies supporting the regulators in implementing policy instruments, for convincing stakeholders (like developers and industry) to implement water efficiency strategies and could include instruments for e.g. rewarding virtuous behaviours (for example: advantageous water tariffs), planning regulations that award planning consent more swiftly or even prescribe the use of water from alternative sources (including recycling).	X	X	X	X		X		Integrated water management (IWM) as a model for "water planning"; demonstration of low cost, modular technologies can be easily retrofitted into any water management infrastructure at district/plant level, hence enabling even small communities and SMEs to implement virtuous practices
SC5-4-2019 869474 WATER-MINING Next generation water-smart management systems: large scale demonstrations for a circular economy and society	Upscaling of the production of biobased products from waste water treatment; extract sustainably phosphate from wastewater; ensure energy efficient nutrients recovery; zero liquid discharge loop system for industrial waste water			X	X		X		Design and test of policy and regulatory measures supporting WATERMINING approach

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
SC5-4-2019 869171 BWater-Smart Promoting water-smart economies and societies in coastal Europe	Development of large-scale systemic innovation approach to select, connect and demonstrate tailored solutions for multiple users and sectors. Demonstration of a range of promising technologies for water reuse and nutrient recovery as well as smart data applications for more efficient resource allocation and use.	X		X			X		Water smart society; approaches include including energy & resource recovery from sea- /wastewater and its residuals, smart management of water systems & infrastructure and small-scale biogas generation, integrated model for safe water reuse (WWTP effluent and/or stormwater) as a source for drinking water and agriculture, combined with water buffers, CE-booster of water reuse in the food industry through a protocol for food-grade water production from treated wastewater. Part of the CIRSEAU cluster (see below).
SC5-4-2019 869496 REWAISE REsilient WAter Innovation for Smart Economy	Paradigm shift towards a carbon-neutral water cycle, addressing the technological, financial, legal and social issues so we can harness the full value of water, considering three key components of economic and social value generated by comprehensive water cycles	X		X		X	X		Part of the CIRSEAU cluster. Mobilisation of water-related investments and synergies with other funding instruments. As well as creating new business opportunities and increasing the competitiveness of EU industries and successful implementation of EU water policies. The CIRSEAU cluster also is looking forward to a sustainable transition to a more circular economy at different scales and economic and social conditions; and increased water security, water use efficiency, enhanced resilience to climate change and achievement of the relevant Sustainable Development Goals

Topic and Title	Main features	A	B	C	D	E	F	G	Main Policy recommendations
SC5-4-2019 869318 ULTIMATE: indUstry water-utiLiTy symbIosis for a sMarter wATer society	ULTIMATE will demonstrate the multiple uses of municipal and industrial wastewater through demonstrations from the agro-food processing, beverage, heavy chemical/petrochemical and biotech industries. Recovery, treatment and reuse of industrial and municipal wastewater, derive and exploit energy, and extract valuable materials contained in industrial wastewater.	X		X	X		X		Part of the CIRSEAU cluster. Development of Water Smart Industrial Symbiosis (WSIS), in which water/wastewater plays a key role within a dynamic socio-economic and business oriented industrial ecosystem. Advanced innovative collaborations between businesses, water service providers, regulators and policymakers for a more circular and socially responsible industry.
SC5-4-2019 869283 WIDER UPTAKE Achieving wider uptake of water-smart solutions	Ensuring that all valuable substances found in wastewater or used water streams are recovered also through overcoming of technological, organisational, regulatory, social and economic barriers.			X	X	X	X		Part of the CIRSEAU cluster. Policymaking may pay more attention to multi-level interactions and varying conditions at the regional and local levels; Policy implementation should be harmonized across regions, but allow a certain degree of flexibility, to enable water-smart symbioses in different local contexts; ✓ For water managers, holistic assessment of local needs and opportunities is recommended before selecting circular economy (CE) strategies

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Other cross cutting projects funded within H2020 have objectives supporting water in the circular economy. They are briefly described below, classified around the main topic of interest:

NATURAL BASED SOLUTIONS AND SMALL TREATMENT SOLUTIONS

TOPIC SCC-02-2016- Demonstrating innovative nature-based solutions in cities – 730283 GROW GREEN Green Cities for Climate and Water Resilience, Sustainable Economic Growth, Healthy Citizens and Environments.

Development of NBS for addressing flooding and heat stress. Platform for embedding NBS in long term urban planning.

TOPIC: SFS-23-2019 - Integrated water management in small agricultural catchments - 862756 OPTAIN - OPtimal strategies to retAIN and re-use water and nutrients in small agricultural catchments across different soil-climatic regions in Europe.

OPTAIN aims to:

(i) identify efficient techniques for the retention and reuse of water and nutrients in small agricultural catchments across different biogeographical regions of Europe, taking into account potential synergies with existing drainage-irrigation systems, and - in close cooperation with local actors –

(ii) select NSWRMs at farm and catchment level and optimize their spatial allocation and combination, based on environmental and economic sustainability indicators.

Natural/Small Water Retention Measures (NSWRMs) are small and multi-functional measures for the retention/management of water and nutrient recovery from water streams. They aim at safeguarding and enhancing the water storage potential of landscape, soils and aquifers, and foster ecosystem services for mitigating the effects of such extreme effects (floods and droughts) (OPTAIN, 2021). Small water retention approaches establish a strong link between agricultural land management and soil-water management for increased nutrient uptake and water retention. The project focuses on affordable and easy-to-implement at the farm level solutions including an economic analysis of proposed measures as well as maintenance of the infrastructure.

TOPIC SC5-27-2020 Strengthening international collaboration: enhanced natural treatment solutions for water security and ecological quality in cities

a) 101003527 MULTISOURCE ModULar Tools for Integrating enhanced natural treatment SOlutions in URban water CyclEs: the project supports citywide planning plus long-term operation and maintenance of nature-based solutions for water treatment for waterborne contaminants removal, storage and reuse in urban areas worldwide. This will enable users to identify multiple sources for local water reuse, promote increased uptake of nature-based solutions and minimise the discharge of inadequately treated water.

b) 101003765 NICE - INNOVATIVE AND ENHANCED NATURE-BASED SOLUTIONS FOR SUSTAINABLE URBAN WATER CYCLE: the project studies existing and innovative NBS covering the urban water cycle (wastewater, greywater, river basins, stormwater and combined sewer overflow), and high-potential solution (green walls, vegetated rooftops, rain gardens and hybrid subsurface wetlands) enhanced with tailored bioaugmentation strategies, reactive materials and other filling media, novel design and plants, to obtain highly efficient urban water NBS.

THE NEXUS: WATER-ENERGY-FOOD-ECOSYSTEM

TOPIC LC-CLA-14-2020: Understanding climate-water-energy-food nexus and streamlining water-related policies

101003881 NEXOGENESIS Facilitating the next generation of effective and intelligent water-related policies utilising artificial intelligence and reinforcement learning to assess the water-energy-food-ecosystem (WEFE) nexus. The project is developing and validating a cross-sectoral policy-making framework, which addresses climate and socioeconomic change, as well as stakeholder behaviour and transboundary (diplomacy) issues. It will also develop a Self-Learning Nexus Assessment Engine (SLNAE), which integrates water-related policies into the WEFE nexus. The project is experimenting the use of strong stakeholder engagement to improve policies and policymaking processes that enhance cooperation and help the EU achieve targets related to the Water Framework Directive, the greener CAP, Green Deal ambitions as well as ambitions on water diplomacy.

7 BIBLIOGRAFY

A.SPIRE. (2013). SPIRE Roadmap. Retrieved from https://www.aspire2050.eu/sites/default/files/pressoffice/spire-roadmap.pdf

A.SPIRE. (2021, Oct). *Processes4Planet SRIA 2050: Processes4Planet: the new A.SPIRE Partnership building on SPIRE results.* Retrieved from A.SPIRE Process4Planet: https://www.aspire2050.eu/p4planet/p4planet-sria-2050

Academy of European Law (ERA). (not available). General Legal Framework on EU Water Law. Retrieved luglio 31, 2022, from https://www.era-comm.eu/EU_water_law/part_2/index.html

Academy of European Law (ERA). (year not available). e-Learning module on EU Water Law. Retrieved from https://www.era-comm.eu/EU_water_law/index.html

Alcalde-Sanz, L., & Gawlik, B. M. (2017). Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge - Towards a water reuse regulatory instrument at EU level. *JRC Science for Policy Report(EUR 28962 EN)*. Luxembourg: Luxembourg: Publications Office of the European Union. doi:10.2760/887727

Ayers, R., & Westcot, D. (1984). *Water quality for Agriculture.* Rome: Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/3/t0234e/t0234e00.htm

BIC. (2017, May). SIRA - Strategic Innovation and Research Agenda BioBased Industries for Development & Growth in Europe. Retrieved from https://www.bbi.europa.eu/sites/default/files/sira-2017.pdf

Biobased Industries Consortium. (2013). Strategic Innovation and Research Agenda (SIRA) - Bio-based and Renewable Industries for Development and Growth in Europe. Retrieved from https://www.bbi.europa.eu/sites/default/files/documents/BBI_SIRA_web_0.pdf

Built4People. (2022, March). Built4People Partnership Strategic Research & Innovation Agenda 2021-2027. Retrieved from https://www.kowi.de/Portaldata/2/Resources/heu/coop/he-built4people-sria-2022-27.pdf

CBE. (2022, June). Strategic Research and Innovation Agenda. Retrieved from file:///C:/Users/ilaria.schiavi/Downloads/cbeju-sria.pdf

Commission of the European Communities. (2007, Mar 22). Towards sustainable water management in the European Union - First stage in the implementation of the Water Framework Directive 2000/60/EC. *COM(2007) 128 final Communication from the Commission to the European Parliament and the Council.* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52007DC0128

Concil of the European Union. (1980). Council Directive 80/778/EEC of 15 July 1980 relating to the quality of water intended for human consumption.

Consolidated version of the Treaty on the Functioning of the European Union. (2016, June 7). *Official Journal of teh European Union, 59(2016/C 202/01)*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:C:2016:202:FULL&from=BG

Council of the European Communities. (1986). Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. *Officila Journal of the European Union, L 181* , 6-12. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31986L0278

Council of the European Union. (1975). Council Directive 76/160/EEC of 8 December 1975 concerning the quality of bathing water.

Council of the European Union. (1976). Council Directive 76/464/EEC of 4 May 1976 on pollution caused by certain dangerous substances discharged into the aquatic environment of the community.

Council of the European Union. (1978). Council Directive 78/659/EEC of 18 July 1978 on the quality of fresh waters needing protection or improvement in order to support fish life.

Council of the European Union. (1979). Council Directive 79/923/EEC of 30 October 1979 on the quality required of shellfish waters as amended by Council Directive 91/692/EEC (further amended by Council Regulation 1882/2003/EC).

Council of the European Union. (1979). Council Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances.

Council of the European Union. (1991). *Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment.* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31991L0271

Council of the European Union. (1991). *Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources.* Retrieved from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A31991L0676

Council of the European Union. (1996). Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.1996.257.01.0026.01.ENG&toc=OJ%3AL%3A1996%3A257%3ATOC

Council of the European Union. (1998). Recast Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A01998L0083-20151027

Council of the European Union. (2020, Oct 26). Position of the Council at first reading with a view to the adoption of a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the quality of water intended for human consumption (recast) - Adopted by the Council on the 23 October 2020. Brussels. Retrieved from https://data.consilium.europa.eu/doc/document/ST-6230-2020-REV-3/en/pdf

Drewes, J. E., Hübner, U., Zhiteneva, V., & Karakurt, S. (2017, Oct 01). Characterization of unplanned water reuse in the EU - Final Report. Technical University of Munich. Retrieved from https://ec.europa.eu/environment/water/pdf/Report-UnplannedReuse_TUM_FINAL_Oct-2017.pdf

EASME and others. (2019). *H2020 Water Innovations for sustainable impacts in industries.* Retrieved from http://www.smart-plant.eu/images/REPORT_Post_workshop_EASME_IWARR2019_30_11_19.pdf

EFFRA. (2016). Factories 4.0 and Beyond - Recommendations for the work programme 18-19-20 of the FoF PPP under Horizon 2020. Retrieved from https://www.effra.eu/sites/default/files/factories40_beyond_v31_public.pdf

Ellen MacArthur Foundation. (2016). *Intelligent assets: unlocking the circular economy potential.* Retrieved from https://ellenmacarthurfoundation.org/intelligent-assets-unlocking-the-circular-economy-potential

Ellen MacArthur Foundation. (2019, Feb). *Circular economy system diagram*. Retrieved from ellenmacarthurfoundation.org: https://ellenmacarthurfoundation.org/circular-economy-diagram

Ellen MacArthur Foundation; Arup; Antea Group. (2019). Water and Circular Economy - A White Paper (Phase 1). Retrieved from https://emf.thirdlight.com/link/v748b66yz2at-r9evus/@/preview/1?o

Estévez, S., González-García, S., Feijoo, G., & Moreira, M. (2022). How decentralized treatment can contribute to the symbiosis between environmental protection and resource recovery. *Science of The Total Environment, 812*. doi:https://doi.org/10.1016/j.scitotenv.2021.151485.

European Commission - DG Environment. (n.d.). *Adapting the management of Water and Environmental Resources in response to Global Change*. (D.-G. f. Environment, Editor) Retrieved from Environment: https://ec.europa.eu/environment/water/adaptation/index_en.htm

European Commission. (17, Jun 1997). Proposal for a COUNCIL DIRECTIVE establishing a framework for Community action in the field of water policy . *Official Journal , C184(COM/97/0049 FINAL)*, 20. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A51997PC0049&qid=1659965693913

European Commission. (1994, Jun 15). Proposal for a Council Directive on the ecological quality of water. . *(COM (93) 680 final)*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:51993PC0680&from=EN

European Commission. (2007, 07 18). Addressing the challenge of water scarcity and droughts in the European Union COM/2007/0414 final. *Communication from the Commission to the European Parliament and the Council*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52007DC0414&qid=1657455128126

European Commission. (2012, 11 14). COM (2012) 673 final - A Blueprint to Safeguard Europe's Water Resources. *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMMITTEE AND THE COMMITTEE OF THE REGIONS*. Brussels. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0673&from=EN

European Commission. (2012, 11 14). Report on the Review of the European Water Scarcity and Droughts Policy. *(COM(2012) 672 final)*. Retrieved from https://climate-adapt.eea.europa.eu/metadata/publications/report-on-the-review-of-the-european-water-scarcity-and-drought-policy/11309505

European Commission. (2012, Nov 15). SWD(2012) 393 final - COMMISSION STAFF WORKING DOCUMENT The Fitness Check of EU Freshwater Policy. Retrieved from https://ec.europa.eu/environment/water/blueprint/pdf/SWD-2012-393.pdf

European Commission. (2013). Factories of the Future. *Multi-annual roadmap for the contractual PPP under Horizon2020*. Luxembourg: Publications Office of the European Union. doi:10.2777/29815

European Commission. (2015). *Closing the Loop - an EU Action Plan for the Circular Economy*. Brussels, Belgium.

European Commission. (2015, Oct 6). Commission Directive (EU) 2015/1787 of 6 October 2015 amending Annexes II and III to Council Directive 98/83/EC on the quality of water intended for human consumption. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2015.260.01.0006.01.ENG&toc=OJ%3AL%3A2015%3A260%3ATOC

European Commission. (2015). Horizon 2020 - Work programme 2014-2015 - 12. Climate action, environment, resource efficiency and raw materials. *European Commission Decision C (2015)7154 of 23 October 2015*. Retrieved from https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/main/h2020-wp1415-climate_en.pdf

European Commission. (2017). Commission notice on guidance document on addressing microbiological risks in fresh fruits and vegetables at primary production through good hygiene. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017XC0523%2803%29

European Commission. (2018, May 28). Impact Assessment accompanying the document "Proposal for a Regulation of the Eu Parliament and of the Council on minimum requirements for water reuse". *Commission Staff Working Document*. Retrieved from https://ec.europa.eu/environment/water/pdf/water_reuse_regulation_impact_assessment.pdf

European Commission. (2019, Dec 11). COM(2019) 640 final - The European Green Deal. Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF

European Commission. (2019). EVALUATION of the Council Directive 91/271/EEC of 21 May 1991, concerning urban waste-water treatment. *Commission Staff Working Document* . Brussels, Belgium.

European Commission. (2019, Dec 13). EVALUATION of the Council Directive 91/271/EEC of 21 May 1991, concerning urban waste-water treatment. *Commission Staff Working Document*. Retrieved from https://ec.europa.eu/environment/water/water-urbanwaste/pdf/UWWTD%20Evaluation%20SWD%20448-701%20web.pdf

European Commission. (2019, Feb 26). Report from the Commission to the European Parliament and the Council on the implementation of the Water Framework Directive (2000/60/EC) and teh Flood Directive (2007/60/EC). Second River Basin Management Plans; First Flood Risk Management Plans. *COM(2019) 95 final*. Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:bee2c9d9-39d2-11e9-8d04-01aa75ed71a1.0005.02/DOC_1&format=PDF

European Commission. (2019, Dec 10). SWD(2019) 439 final FITNESS CHECK of the Water Framework Directive, Groundwater Directive, Environmental Quality Standards Directive and Floods Directive. *Commission Staff Working Document*. Retrieved from https://ec.europa.eu/environment/water/fitness_check_of_the_eu_water_legislation/documents/Water%20Fitness%20Check%20-%20SWD(2019)439%20-%20web.pdf

European Commission. (2020). *A New Circular Economy Action Plan - for a Cleaner and More Competitive Europe*. Brussels, Belgium. Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

European Commission. (2020, 03 10). A New Industrial Strategy for Europe COM(2020) 102 final. *COMMUNICATION FROM THE COMMISSION*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1593086905382&uri=CELEX:52020DC0102

European Commission. (2020, 03 10). An SME Strategy for a sustainable and digital Europe-COM (2020) 103 Final. *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1593507563224&uri=CELEX:52020DC0103

European Commission. (2020, May 20). COM(2020) 380 final EU Biodiversity Strategy for 2030 Bringing nature back into our lives. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX:52020DC0380

European Commission. (2020). COM(2020) 381 final - A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381

European Commission. (2020, Oct 14). COM(2020) 667 final Chemicals Strategy for Sustainability - Towards a Toxic-Free Environment. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*. Retrieved from https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf

European Commission. (2020, Nov 25). COM(2020) 761 final Pharmaceutical Strategy for Europe. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0761

European Commission. (2020, 09 03). Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability COM(2020)474 final. *Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0474&from=EN

European Commission. (2021, May 12). COM(2021) 400 final Pathway to a Healthy Planet for All - EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil'. *Communication from the Commission to the European Parliament, the Council, the European Economic* *and Social Committee and the Committee of the Regions*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0400&qid=1623311742827

European Commission. (2021). COM(2021) 699 final - EU soil strategy for 2030 Reaping the benefits of healthy soils for people, food, nature and climate. *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699

European Commission. (2021, Nov 17). COM(2021) 699 final EU Soil Strategy for 2030 Reaping the benefits of healthy soils for people, food, nature and climate. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699

European Commission. (2021, July 14). *Commission presents Renewable Energy Directive revision*. Retrieved from https://ec.europa.eu/info/news/commission-presents-renewable-energy-directive-revision-2021-jul-14_en

European Commission. (2021, June). Water in the Circular Economy policy development. *Workshop report with findings from demo cases of Horizon2020 projects*. Retrieved from https://watereurope.eu/wp-content/uploads/Report_Water-in-the-Circular-Economy-policy-development.pdf

European Commission. (2022, March 8). COM(2022) 108 final REPowerEU: Joint European Action for more affordable, secure and sustainable energy. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*. Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:71767319-9f0a-11ec-83e1-01aa75ed71a1.0001.02/DOC_1&format=PDF

European Commission. (2022, Aug 05). Guidelines to support the application of Regulation 2020/741 on minimum requirements for water reuse - Commission notice. *Official Journal of the European Union*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.C_.2022.298.01.0001.01.ENG&toc=OJ%3AC%3A2022%3A298%3ATOC

European Commission. (2022, Oct 26). Proposal for a Directive of the European Parliament and of the Council concerning urban waste water treatment (recast). Retrieved from https://environment.ec.europa.eu/publications/proposal-revised-urban-wastewater-treatment-directive_en

European Commission. (2022, Oct 26). SWD(2022) 541 final Impact Assessment Accompanying the document Proposal for a Directive of the European Parliament and of the Council concerning urban wastewater treatment (recast). *Commission Staff Working Document*. Retrieved from https://environment.ec.europa.eu/publications/proposal-revised-urban-wastewater-treatment-directive_en

European Commission and EFFRA. (2021). Made in Europe- The manufacturing partnership in Horizon Europe - Strategic Research and Innovation Agenda (SRIA). Retrieved from https://www.effra.eu/sites/default/files/made_in_europe-sria.pdf

European Commission. (n.d.). *CORDIS search results on projects related to call H2020-WATER-2014-2015*. Retrieved 2022, from CORDIS: https://cordis.europa.eu/search?q=contenttype%3D%27project%27%20AND%20%2Fproject%2Frelations%2Fassociations%2FrelatedMasterCall%2Fcall%2Fidentifier%3D%27H2020-WATER-2014-2015%27&p=1&num=10&srt=Relevance:decreasing

European Council. (1991). Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC) - consolidated text. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1561542776070&uri=CELEX:01991L0676-20081211

European Environment Agency. (2022). *Beyond water quality — Sewage treatment in a circular economy.* EEA Report No.05/2022. Retrieved from https://www.eea.europa.eu/publications/beyond-water-quality-sewage-treatment

European Environmental Agency. (2012). Euopean waters - current status and future challenges. *EEA Report No 9/2012*. Brussels. Retrieved from https://www.eea.europa.eu/publications/european-waters-synthesis-2012

European Environmental Bureau (EEB). (2005). *EU Environmental Policy Handbook.* Stefan Scheuer. Retrieved from https://www.academia.edu/9926619/EU_Environmental_Policy_Handbook?auto=download

European Parliament and Council of the European Union. (2000, Dec 22). 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. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060

European Parliament and the Council. (2013). REGULATION (EC) No 294/2008 establishing the European Institute of Innovation and Technology as amedned by REGULATION (EU) No 1292/2013. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008R0294-20140101&qid=1412257633975&from=EN

European Parliament and the Council. (2018, 07 05). DIRECTIVE 2008/98/EC on waste and repealing certain Directives (Consolidated text) of 19 November 2008. Brussels. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008L0098-20180705#B-1

European Parliament and the Council. (2020, May 25). *Regulation (EU) 2020/741 on minimum requirements for water reuse.* Retrieved from Official Journal of the European Union: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0741&from=EN

European Parliament and the Council of the European Union. (2010, Nov 24). Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (recast). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010L0075

Fatone, F., Loederer, C., Wintgens, T., Álvarez Rodríguez, J. A., & Hospido, A. (2017). Municipal wastewater treatment to deliver circular economy in the water sector. *9th International conference on environmental engineering and management - Circular Economy and environmental sustainability.* Bologna. Retrieved 2022, from https://www.smart-plant.eu/images/publications/circular-economy/9_PPT_Municipal%20WWT%20to%20deliver%20circular%20economy%20____ICEEM%2009%20FATONE.pdf

Fidelis, T., Cardoso, A. S., Riazi, F., Miranda, A. C., Abrantes, J., Teles, F., & Roebeling, P. C. (2021). Policy narratives of circular economy in the EU e Assessing the embeddedness of water and land in national action plans. *Journal of Cleaner Production 288*, 125685.

Foglia, A., Bruni, C., Cipolletta, G., Eusebi, A. L., Frison, N., Katsou, E., . . . Fatone, F. (2021). Assessing socio-economic value of innovative materials recovery solutions validated in existing wastewater treatment plants. *Journal of Cleaner Production, 322*. doi:https://doi.org/10.1016/j.jclepro.2021.129048

Giakoumis, T. V. (2018). The Transition of EU Water Policy Towards the Water Framework Directive's Integrated River Basin Management Paradigm. *Environmental Management, 62*, 819–831. doi:https://doi.org/10.1007/s00267-018-1080-z

Guidelines on Integrating Water Reuse into Water Planning and Management in the context of the WFD. (2016). *COMMON IMPLEMENTATION STRATEGY FOR THE WATER FRAMEWORK DIRECTIVE AND THE FLOODS DIRECTIVE.* Retrieved from https://ec.europa.eu/environment/water/pdf/Guidelines_on_water_reuse.pdf

ISO. (2020). ISO 22449-1 Use of reclaimed water in industrial cooling systems - Technical guidelines. *International Standard.*

ISPT. (2021). *ECWRTI WHITE PAPER.* Retrieved from All publications for EU-WT-00 project: https://ispt.eu/publications/?project-tag=EU-WT-00

JRC. (2012). A multi-criteria optimisation of scenarios for the protection of water resources in Europe. *JRC Scientific and Policy Reports*. Retrieved from https://ec.europa.eu/environment/water/blueprint/pdf/EUR25552EN_JRC_Blueprint_Optimisation_Study.pdf

Kaika, M. (2003). The Water Framework Directive: A New Directive fora Changing Social, Political and Economic EuropeanFramework. *European Planning Studies, 11(3)*. Retrieved from https://www.researchgate.net/publication/228710668_The_Water_Framework_Directive_A_New_Directive_for_a_Changing_Social_Political_and_Economic_European_Framework

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, 127*, 221-232. doi:https://doi.org/10.1016/j.resconrec.2017.09.005.

Ministerio de la Presidencia. (2007, Dec 08). REAL DECRETO 1620/2007, de 7 de diciembre, por el que se establece el régimen jurídico de la reutilización de las aguas depuradas. *Boletín Oficial del Estado*. Agencia Estatal Boletín Oficial del Estado. Retrieved from https://www.boe.es/diario_boe/txt.php?id=BOE-A-2007-21092

Ministero dell'ambiente e della tutela del territorio. (2003, 07 23). DECRETO 12 giugno 2003, n. 185. Regolamento recante norme tecniche per il riutilizzo delle acque reflue in attuazione dell'articolo 26, comma 2, del decreto legislativo 11 maggio 1999, n. 152. *Gazzetta Ufficiale della Repubblica Italiana, Serie Generale n.169*. Retrieved from https://www.gazzettaufficiale.it/eli/id/2003/07/23/003G0210/sg

NASA. (2021). *Freshwater Availability Toolkit*. Retrieved from NASA Earth Data: https://www.earthdata.nasa.gov/learn/toolkits/freshwater-availability-toolkit

NextGen. (2022). *NextGen Policy Brief: Solutions for a Water-Smart, circular and resilient Urban Wastewater Treatment and Sewage Sludge Directives.* Retrieved from WaterEurope: https://watereurope.eu/wp-content/uploads/20221004_nextgen_PolicyBrief_Brochure-PRINT.pdf

Nika, C., Vasilakia, V., Renfrewa, D., Danishvarb, M., Echchelha, A., & Katsou, E. (2022). Assessing circularity of multi-sectoral systems under the Water-Energy-Food-Ecosystems (WEFE) nexus. *Water Research, 221*. doi:https://doi.org/10.1016/j.watres.2022.118842

Smol, M. A. (2020). Circular economy model framework in the European water and wastewater sector. *Journal of Material Cycles and Waste Management, 22*, 682–697. doi:https://doi.org/10.1007/s10163-019-00960-z

Stanchev, P., Vasilaki, V., Dosta, J., & Katsou, E. (2017). Measuring the circular economy of water sector in the three-folding linkage of water, energy and materials. *Proceedings of the 5th international conference on sustainable solid waste management.* Athens. Retrieved from https://www.smart-plant.eu/images/publications/circular-economy/1_Athens2017_Stanchev_Vasilaki_Mousavi_Dosta_Katsou.pdf

UNESCO. (2021). *UN World Water Development Report 2021.* Retrieved from United Nations World Water Development Report: https://www.unesco.org/reports/wwdr/2021/en

UNESCO World Water Assessment Programme. (2017). *The United Nations world water development report, 2017: Wastewater: the untapped resource.* Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000247153

Water Europe. (2016). The value of water - Multiple waters for multiple purposes and users. Retrieved from https://watereurope.eu/wp-content/uploads/2020/04/WE-Water-Vision-english_online.pdf

Water Europe. (2021). *Unlock the potential of the sewage sludge directive through the full exploitation of the value in water for a green and sustainable Europe.* Retrieved from https://watereurope.eu/wp-content/uploads/WE-Position-Paper-on-the-Sewage-Sludge-Directive.pdf

WATER4All. (2021, Feb 08). *2nd Draft Strategic Research and Innovation Agenda.* Retrieved sept 2022, from http://www.waterjpi.eu/implementation/water-challenges-in-horizon-europe/water4all-_2nd_draftsria_08022021_fordistribution.pdf

WATER4All. (n.d.). *EUROPEAN PARTNERSHIP WATER4ALL – WATER SECURITY FOR THE PLANET* . Retrieved 2022, from WATER4All: http://water4all-partnership.eu/

WaterEurope. (2016). Multiple waters for multiple purposes and users - Strategic Innovation and Research Agenda. Retrieved from https://watereurope.eu/wp-content/uploads/2019/07/Water-Europe-SIRA.pdf

Yua, Y., Šuligoj, A., Shidlovsky, Z., Shachar, D., Yaron, S., & Paz, Y. (2022, Apr 01). Towards on-demand photocatalysis: Controlling the operation of a photocatalytic reactor based on real-time, automatic monitoring of toxicity towards the working bacteria of a proceeding bioreactor. *Chemical Engineering Journal, 433*. Elsevier. doi:https://doi.org/10.1016/j.cej.2021.133621