D7.6 NextGen final report

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Summary

NextGen successfully demonstrated circular water solutions encompassing a wide range of water-embedded resources, and revealed the conditions for transfer and upscale. The project has challenged embedded thinking and practices in the water sector by embracing circular economy principles and technological innovation.

The circular economy (CE) is an emerging system that moves away from the traditional linear view of 'make, use, and dispose' to one that is restorative and regenerative to keep resources, such as water, at its highest value at all times. Water is essential to the CE due to its importance for human life, its use and value in numerous economic sectors, and because of the energy and material it contains. A radical redesign of water services to deliver a new generation of validated, progressive solutions to underpin the CE model is urgently required.

The main objectives of the EU H2020-project NextGen are to develop and demonstrate novel technological, business and governance solutions for water in the CE in ten high-profile, large-scale, demonstration cases across Europe, and to develop the necessary approaches, tools and partnerships, to transfer and upscale. The CE transition to be driven by NextGen encompasses a wide variety of water-embedded resources: water itself, energy and materials (e.g. nutrients).

All results of the NextGen activities are published at the project website: NextGen - Circular Water Solutions. To ensure the long-term sustainability and as part of creating the water in the CE marketplace, all our results from the demo cases, circular water technologies, products and tools are accessible on the Water Europe Marketplace established by NextGen: Water Europe Marketplace.

This document (*D7.6 NextGen final report*) presents the key messages derived from the main results and outcomes (see *D7.5 Synergies report*):

- NextGen unlocked the potential of the circular economy in the water sector, by **demonstrating the recovery and reuse of water-embedded resources** in ten demo cases spread across different European regions in eight countries.

- NextGen demonstrated the benefits of circular water solutions in **reducing** water, energy and materials consumption, in **prevention** of pollution to water ecosystems and the environment, and in providing **added value** of recovered resources to be used in other sectors to implement symbiotic approaches of the circular economy.

- NextGen has launched a Water Europe online match-making **marketplace** for products and services, that showcases circular water **technologies**, environmental and economic assessment **tools**, and **best practices** to implement circular economy solutions.

- NextGen **informed relevant policy**, suggesting that there is a clear need for better aligned EU directives that incentivise circularity, improve clarity and transparency for the

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implementation of the Water Reuse Regulation, and highlighted the need for dedicated end-of-waste criteria that simplify the process of less costly routes to market for recovered resources.

- NextGen provided evidence-based knowledge on enabling framework **conditions** for the transition to a circular economy in the water sector, including **societal acceptability**, **circular value chains and business models**, and supportive **policy and regulations**.

An overview of the demonstrated NextGen circular water technologies at the demo cases and the achieved impact is presented in Annex A.

The *Infographic* accompanying this final report: https://nextgenwater.eu/wp-content/uploads/2022/11/Key-Results-PDF.pdf

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Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°776541

1. Demonstrating the recovery and reuse of water-embedded resources

Key message #1:
NextGen unlocked the potential of the circular economy in the water sector, by demonstrating the recovery and reuse of water-embedded resources in ten demo cases spread across different European regions in eight countries.

At the ten NextGen demo cases, 26 circular water technologies have been implemented and tested. The project went beyond current approaches that target incremental improvements of water, resource and energy efficiency and provided a whole value chain, CE approach demonstrated at large scales, ensuring ***EU added value***. The different demonstrated innovative solutions displayed that technically we can transform wastewater into valuable and high-quality products such as reclaimed water, energy (biogas and heat), and/or recovered materials (including nitrogen and phosphorous). We demonstrated how these products can act as alternative sources to cover a range of (non-potable) water demands, energy needs and the production of fertilisers and other commercial goods. An overview of the demonstrated technologies and the ***achieved impact*** is presented in Annex A.

Water
For closing the water cycle, innovative technologies and studies were tested and demonstrated to promote alternative water sources obtaining high quality water for non-potable uses according to the concerning legislations and regulations. These technologies included wastewater advanced treatments and rainwater harvesting and storage systems.

Energy
Three energy recovery practices were demonstrated for closing the energy cycle: heat recovery from wastewater and local reuse, biogas production from sewage sludge, and heat storage and recovery.

Materials
Solutions were demonstrated for material recovery from sludge, protein production from wastewater (from brewery and urine) and/or RO concentrate, nitrogen removal and recovery, phosphorus removal and/or recovery and the impact of low-flow wastewater on nutrient concentrations. The technologies tested demonstrated that it is possible to obtain high quality materials from wastewater that can be used as substitute of chemically obtained products, such as fertilizers used for agricultural purposes.

Technological Evidence Base
A Technology Evidence Base (TEB) was established that presents generic information about the demonstrated circular technologies and the case study specific results. NextGen developed and uploaded 26 technology factsheets and 10 case studies factsheets including their results. The TEB aims to unify the results and to allow for an easy access to relevant information needed for setting up a new circular economy scheme in the water sector. The TEB is accessible via Water Europe Marketplace.

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2. Reducing consumption, prevention of pollution, and added value of recovered resources

Key message #2:
NextGen demonstrated the benefits of circular water solutions in reducing water, energy and materials consumption, in prevention of pollution to water ecosystems and the environment, and in providing added value of recovered resources to be used in other sectors to implement symbiotic approaches of the circular economy.

By introducing innovative solutions for closing the cycles of the water system, NextGen contributes to the challenges of water scarcity, raw materials depletion and climate change, based on proven, successful experiences. Our technologies are able to decrease resource abstraction from nature and waste disposal to nature. See Annex A for ***quantified impact***.

Environmental assessment
Life Cycle Assessments demonstrated that CE concepts and technologies can lead to a lower environmental footprint of wastewater treatment, considering the value of recovered products and the substitution of conventional alternatives from the linear economy. However, we also emphasised that the specific situation at the site is very important to allow the full potentials of these solutions to be realized. For energy recovery from wastewater or sludge, in particular, our work illustrated that it is important to assess the total energy balance of these systems rather than focusing only on the additional biogas or heat recovered. Through Quantitative Microbial Risk Assessment we demonstrated the potential for safe implementation of water reuse applications for almost all tested treatment configurations.

Economic assessment
Life Cycle Costing and Cost Effectiveness Analysis revealed that within the given market and regulatory context small-size local circular solutions do have a higher specific treatment cost, and that the price of reuse water is not always competitive with the current local drinking water price. However, other aspects need to be considered: for example we found that in several cases anaerobic wastewater treatment, resulted in a cost for CO_2-eq reduction that is lower than the current CO_2-eq price. Still, overall few circular technologies are cost effective with regards to climate mitigation. Although P recovery from sludge at one demo case was cost effective compared to mineral P, most nutrient recovery systems are not profitable at this stage, as the revenues from fertilisers are lower than the cost of the recovery. However, the cost effectiveness of the assessed technologies will improve as they are further developed and reach market maturity. Moreover, more advanced use of economic instruments such as pricing, taxing and subsidies (green bonds) can improve the competitiveness of circular products.

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3. Marketplace for the uptake of circular water solutions

Key message #3:
NextGen has launched a Water Europe online match-making marketplace for products and services, that showcases circular water technologies, environmental and economic assessment tools, and best practices to implement circular economy solutions.

NextGen created new market opportunities, services, and solutions throughout the water cycle. The project applied a high-impact ***exploitation potential*** strategy, with the creation of an online CE Marketplace, new business models and value chains, and spinoffs to widely commercialise project technologies

Marketplace
NextGen developed the Water Europe Marketplace for a circular economy (https://mp.watereurope.eu/), a flexible platform that provides solutions and technologies in water, energy, and materials and supports the market uptake of those innovations. It connects problem owners and solution providers in an online platform.

The CE Marketplace provides a comprehensive database of technology factsheets (such as for struvite precipitation, anaerobic Membrane BioReactor, sludge pyrolysis, sewer mining, etc.), environmental and economic assessment tools and products (such as Life Cycle Assessment, Life Cycle Costing, Cost Efficiency Analysis, Quantitative Microbial Risk Assessment, Urban Water Optioneering Tool, HydrOptim, Augmented Reality, Serious Games) and results from the NextGen demo cases.

Circular value chains
To further support the market uptake, new business models are required across the whole water value chain. Moving from a linear to a circular economy entails a shift from a financial cost-benefit approach to a business model based on circular value chains. The project developed a circular business canvas and identified 23 circular value chains from the ten NextGen demo cases. Business plans have been developed for spinoffs of NEWater Source for water reuse in France (i.e. sewer mining), and a joint cooperation for upcycling water residuals (i.e. recovered calcite).

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4. Supportive policy and regulations

Key message #4:
NextGen informed relevant policy, suggesting that there is a clear need for better aligned EU directives that incentivise circularity, improve clarity and transparency for the implementation of the Water Reuse Regulation, and highlighted the need for dedicated end-of-waste criteria that simplify the process of less costly routes to market for recovered resources.

Policy relevance
The EU's Circular Economy Action Plan strives for the transition of the European economy from a linear to a circular model. However, tensions between different regulatory frameworks need to be reconciled as the CE is very much a transition from waste management and disposal towards value creation within and between sectors.

Based on the experiences of the NextGen demo cases, the project recommends adaptation of policy and regulatory frameworks within the scope of EU legislation, highlighting the need for an improvement of clarity and transparency for the ***Water Reuse Regulation***, and a better alignment between directives and incentivise circularity. For example, include the water sector in energy efficiency and renewable energy strategies, but improve alignment with environmental ambitions.

The recently proposed revision of the ***Urban Wastewater Treatment Directive*** is a step in the right direction towards a CE, as it seeks to drive the water and wastewater sector towards energy neutrality, and provides greater incentive for water reuse and the recovery of biogas and phosphorus.

We recommend the creation of dedicated end-of-waste criteria for a simpler, and less costly routes to market for recovered resources. Many gaps and hurdles still exist, although the recently revised ***Fertilising Products Regulation*** opens the single market for fertilisers produced from recovered or organic materials, including those from (waste)water.

Further, de-risked financing can be used to support investment in circular water solutions and progress the technological development. The project recommends that circular water systems can be targeted with green bonds through an adapted EU ESG (Environmental Social Governance) / green financing system.

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5. Enabling conditions for the transition to a circular water economy

Key message #5:
NextGen ten demo cases provide evidence-based knowledge on enabling framework conditions for the transition to a circular economy in the water sector, such as societal acceptability, circular value chains and business models, and supportive policy and regulations.

The project identified at the ten NextGen demo cases 12 key drivers, 20 key barriers and 20 key support measures to the upscaling of circular water solutions. To enable the shift from a linear to a circular water economy, both technological, economic, regulatory and socio-cultural (*this section*) instruments are needed.

Societal acceptability
Public acceptance is of utmost importance as the people are end-users of water and its recovered resources. In contrast to the general belief, most people are positive towards reclaimed water and recovered products. A large survey was conducted in the UK, the Netherlands and Spain, that revealed a generally positive attitude, i.e., 70-80% of the respondents indicated to (strongly) support using recycled water for drinking purposes and eating food grown with recovered nutrients. Public acceptance can be further enhanced by legitimisation strategies that address social norms and emotional reactions, such as the use of long-term narratives and positive framing around the benefits of circular water solutions so that recycled water becomes ‘normalised’.

Stakeholder engagement
A circular water economy requires the active engagement from relevant stakeholders. Stakeholders across the water value chain are involved in Community of Practice (CoPs) meetings at the demo cases. Through social learning processes, the CoPs positively contributed to engagement and interaction of stakeholders, change in stakeholders issue frames, and stakeholder awareness of role and competence.
Stakeholder and in particular citizen engagement, can be enhanced by virtual visualisation platforms such as Augmented Reality app (AR) and Serious Games (SG) in which the general public can experience circular water solutions. A NextGen Augmented Reality app CirculAR and the NextGen Serious Game were built and demonstrated for that purpose. Results show the high potential of increasing public understanding and acceptance through AR and SG.

Transition to a circular water economy
A comprehensive package of EU enabling instruments at short-term is required, as all four conditions for a circular water economy will have to be successfully created simultaneously:

- circular water technologies, that are sustainable at system level
- economic viability, based on circular value chains
- societal acceptance, along with engaged stakeholders
- adapted governance, with supportive regulations.

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6. Final reflections

Next to the listed key messages derived from the NextGen demonstrations and research, we present some of our opinions regarding water in the CE at the end of the project.

The water sector provides for a healthy society and clean environment. Over the last decade, the sector has done so in a more **sustainable** way by using less resources itself, i.e. water, materials and most noticeably less energy. The next step is to do so in a more **circular** way by recovering and reusing water, materials (nutrients) and energy, not only in the water sector itself, but also as part of the overall circular economy. NextGen successfully **demonstrated** the recovery and reuse of water-embedded resources, leading the way to a circular water economy.

Several of the demonstrated CE technologies provide multiple services aimed at water, energy and materials recovery and reuse. Indeed, we need to look more at **synergies** between these resource flows, rather than keep designing and operating the relevant systems in isolation. NextGen confirmed that recovery comes at a cost. Although circular water solutions can lead to a lower environmental footprint, the recovery and reuse process often requires more energy and may accumulate contaminants. A **system perspective**, e.g. total energy balance, needs to be taken and a stronger collaboration between the water and clean energy sectors is warranted.

NextGen also looked at circular water solutions from a resilience and sustainability perspective and created the tools and concepts needed for such assessments at the system level. We argued that “circular” does not mean by default “resilient” and “resilient is not necessarily the same as sustainable, so these different desirable properties need to be assessed in combination. During the project’s execution, another aspect that became more prominent, due to the challenges the EU faces (including pandemic and warfare), was the preference for solutions that increase autonomy and **self-sufficiency**. NextGen made a strong case for the need to continue and intensify efforts towards more **autarkic** solutions where water, energy and materials are fully regenerated.

We expect that Research and Innovation (R&I) will continue to improve the performance and applicability of CE interventions and to develop new circular technologies with acceptable risks. We further expect those CE interventions in turn to play an increased role in better adapting to climate change. To this effect R&I will have to work with and co-create within a pro-active societal environment that aligns policies, technologies and societal values. NextGen demonstrated the added value to **engage society** in devising our solutions, and proved that public opinion is mostly positive towards reclaimed water and recovered products from wastewater. The momentum for change seems to be here.

The successful uptake of circular water solutions also depends on economic viability. The cost effectiveness of NextGen technologies, and other similar technologies inspired by our work, will improve as they are further developed and reach market maturity. However, the move towards a CE entails a shift from a financial cost-benefit approach to a business model based on **circular value chains**. As such we need to **rethink the system** to legitimise a more

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circular utilisation of water. This implies the re-design of the contextual setting, practices, technologies, policies, legislative frameworks and indeed our way of thinking.

The transition from a focus on “waste management and disposal” towards value creation within and between sectors asks for an **adapted regulatory framework**. Ultimately, to support wide uptake of circular water solutions across the EU, a comprehensive ‘package’ of enabling instruments at short-term is required, consisting of technological, economic, socio-cultural and regulatory measures.

A kind of **‘EU CE Blue Deal’** could provide for such an enabling package. We advocate a Blue Deal, building on the CE Action Plan and revised water regulations that sensitize CE, tackling both water security and sustainability, addressing climate change but also benefiting the path to **biodiversity** recovery.

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Annex A: Quantified impact of NextGen circular water solutions at the demo cases

Demo Case	Technology	Water use Energy use Recovered Product	Quantified impact
Braunschweig	Thermal hydrolysis and two-stage digestion	Reuse within WWTP: Digestion, CHP and buildings	Feed with dry matter 10-13% of wet weight; Increase in biogas production: 20%
Braunschweig	Air stripping and scrubbing	Ammonium sulphate	TRL 9 à recovery: N: 85-97%; 7-19 m³ liquor/h; 380 000 PE: 175 t N/a
Braunschweig	CO2 stripping and precipitation	Struvite	TRL 9 à recovery: P: 80-97%; 7-19 m³ liquor/h; 380 000 PE: 37 t P/a & 17 t N/a
Costa Brava	Ultrafiltration + regenerated reverse osmosis membranes	Private use	TRL 7; 2 m³/h
Westland	Aquifer storage and recovery / water banking	Horticulture irrigation	Theoretical study; aquifer rainwater storage: 4.8 Mm³/y; 80 % reduction of net groundwater extraction
Westland	Aquifer thermal energy storage	Heating demand for horticulture	4200 MWh/y charged, and 3750 MWh/y discharged; Heat recovery factor: 0.89
Altenrhein	Pyrolysis	Granular activated carbon	TRL 7 à recovery: 50% GAC, 50% gas, sieving losses; 1 kg dried sludge/h; Suitable as pre-treatment for conventional GAC filter
Altenrhein	Hollow fibre membrane contactor	Ammonium sulphate	TRL 8 à recovery: N: 75%; 8.5 m³ centrate/h; 305 000 PE: 66 t N/a
Altenrhein	Thermal treatment	PK fertiliser	TRL 8 à recovery: P: 90-100%; 50 kg dried sludge/h; 305 000 PE: 260 t P/a
Spernal	Anaerobic membrane bioreactor	Farming and industrial use	TRL 7; 500 m³/d
Spernal	Decentralized energy recovery and usage from anaerobic MBR	Reuse within the WWTP or export of electricity or biomethane to grid	200 m3/day; Electricity & heat produced for two scenarios: 1.CHP-electricity and heat: 44 kWh/day and ~ 50kWh heat/d 2. Biogas upgrading: 108 kWh/d
Spernal	Ion exchange and hollow fibre membrane contactor	Ammonium sulphate	TRL 6: recovery: N > 76%, IEX >80%, HFMC >95%; 1 m³ AnMBR effluent/d; 100 000 PE: 320 t N/a
Spernal	Ion exchange and precipitation	Hydroxyapatite	TRL 6 à recovery: P: > 72%; IEX >80%; precipitator >90%; 1 m³ AnMBR effluent/d ; 100 000 PE: 61 t P/a

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La Trappe	Metabolic network reactor + MELiSSA Microfiltration/reverse osmosis membranes	Bottle washing, aeroponics and aquaculture	TRL 7; 100 L/h
La Trappe	Photobioreactor	Proteins as slow release fertiliser	TRL 5-6 à recovery: COD: 38%, N: 20%, P: 25%; 60 L wastewater/d; Pilot: 276-575 kg dried biomass/a
Gotland	Decentralized reverse osmosis membrane system	Indirect drinking water supply	TRL 7; 1.6 m^3/h
Gotland	Innovative floodgate and real time measurements for water balance	Urban and agricultural use	TRL 7; storage: 100 000 m^3/y, 25 % of water savings per year
Athens	Membrane bioreactor (sewer mining unit)	Urban irrigation and other non-potable use	TRL 8; 25 m^3/d
Athens	Heat exchanger and heat pump	Boost Composting unit operation + office heating/cooling/showers	Inflow 25 m3/day/1- 10 kW; Small-scale heat recovery system efficiency: - COP heating: 4.0-5.12 - EER cooling: Min. 3-4.85
Athens	Rapid composting bioreactor	Compost	TRL 7 à recovery: C: 60%, N:80%, P: 100%; 5 t compost/a; 600 PE: 1 t N/a & 0.34 t P/a
Filton Airfield	Alternative water source (i.e., rainwater)	Toilet flushing and public irrigation	Theoretical study; 10 – 75 % of water savings per year
Filton Airfield	Simulation-based study	Domestic use-space and water heating	41 m3/day; 38,788 kWh/year recovered (theoretical)
Timişoara	Feasibility study on reclaimed water production	Urban, industrial and agricultural use	Theoretical study; 10 800 m^3/h
Timişoara	Pyrolysis	Pyrolysis gas, oil and char	TRL 4 à recovery: 18% gas, 63% char, 2% oil; 2.1 kg dried sludge/h; 400 000 PE: 3100 m^3 gas/d

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