nextGen
Circular Water Solutions

D7.5 Synergies Report

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Summary

The main objectives of the EU H2020 NextGen Project, were to develop and demonstrate novel technological, business and governance solutions for water in the circular economy (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 driven by NextGen encompasses a wide range of water-embedded resources: water itself, energy, and materials (e.g. nutrients). This *D7.5 Synergies report* serves as an extensive summary of the main results and outcomes of NextGen.

NextGen worked on ten demonstration sites across Europe providing evidence demonstrating the feasibility of innovative technological solutions. Through the demonstration cases, 26 circular water technologies have been implemented and tested. The innovative solutions demonstrated, provided evidence that we can, technically, 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. Technology factsheets and the demonstrated results and quantified impact at the demo cases have been assembled in a Technology Evidence Base.

Detailed assessments were carried out for both existing and new technologies providing sound evidence of environmental and economic performance and clearly identifying risks and improvement option. Life Cycle Assessments (LCA) 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. Through quantitative microbial risk assessment (QMRA) of water reuse we demonstrated the potential for safe implementation of water reuse applications for almost all tested treatment configurations. Our economic assessments also provided important lessons on site-specificity and competitiveness of circular solutions. It was highlighted for example 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 is expected to improve as they are further developed and reach market maturity.

NextGen argued that the transition to a circular water economy requires the active engagement from relevant stakeholders. As such, we created an engaging environment and developed an innovative framework of systematic and holistic engagement activities. At the demo cases, the NextGen solutions have been consulted with a broad representation of stakeholder groups in Communities of Practices (CoP). The CoPs positively contributed to

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engagement and interaction of stakeholders, change in stakeholders issue frames, and stakeholder awareness of their own role and competence and of those of other members. Citizen engagement was effectively enhanced by our virtual visualisation platforms in which the public can experience circular water solutions: Augmented Reality app CirculAR and the NextGen Serious Game Toy Town.

Societal acceptance is of the utmost importance as the people are in effect the final end-users of water and its recovered resources. Contrary to the general belief, results from three large-scale surveys of the public in the UK, the Netherlands and Spain show that public support for circular solutions is high. The proportions of respondents who (strongly) supported the use of recycled water for drinking were 67% to 75%, and for the use of recovered nutrients to grow food were 74% to 85%.

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. A circular business canvas has been established and 23 circular value chains from the demo cases have been identified. For selected circular solutions, a market assessment and business plans have been developed. But we also took a step further towards exploitation: we launched three spin-offs to fully pursue the potential of several of our solutions in the real world.

NextGen developed the Water Europe Marketplace for a circular economy, 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 open access platform. NextGen results are available in the CE Marketplace in the Technology Evidence Base (factsheets and demo cases results) and Toolkit (products and assessment tools).

Based on the experiences of the NextGen demo cases, we recommended potential 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. Further, we recommended the creation of simpler, and less costly routes to market for recovered resources. 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.
Ultimately, to support the EU wide uptake of circular water solutions, a comprehensive ‘package’ of enabling instruments at short-term is required, consisting of technological, economic, socio-cultural and regulatory measures.

NextGen results have been communicated across multiple online and in-person channels and in academic outreach events. Through discussion sessions and our policy briefs we connected to EU policy makers and shared our results and recommendations.

We successfully demonstrated circular water solutions at our demo cases, encompassing a wide range of water-embedded resources, and we revealed the conditions for transfer and upscale. Hence, NextGen challenged embedded thinking and practices in the water sector by embracing circular economy principles and technological innovation.

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1. Introduction

1.1 Background and objectives

This *D7.5 Synergies report* presents an extensive summary of the main results and outcomes of the NextGen project on circular water solutions.

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 (project number 776541) 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 range of water-embedded resources: water itself, energy and materials (e.g. nutrients).

NextGen goes beyond current approaches that target incremental improvements of water, resource and energy efficiency and provides a whole value chain, CE approach demonstrated at large scales. Its technologies, services and business models, are able to decrease resource abstraction from nature and waste disposal to nature. The project bridges the gap between investment needs and available funds by creating new services. It assembles innovative sites in Europe and combines circular water solutions with tested tools for active involvement of stakeholders. 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.

1.2 Project structure

The NextGen consortium consist of 31 partners (plus 3 international and associated partners), see Annex A. KWR is the project coordinator.

NextGen is organised in 6 Work Packages (plus WPs on project management and ethic requirements), see Figure 1.1. At the centre of NextGen are the 10 demo cases across 8 European countries (see Figure 1.2).

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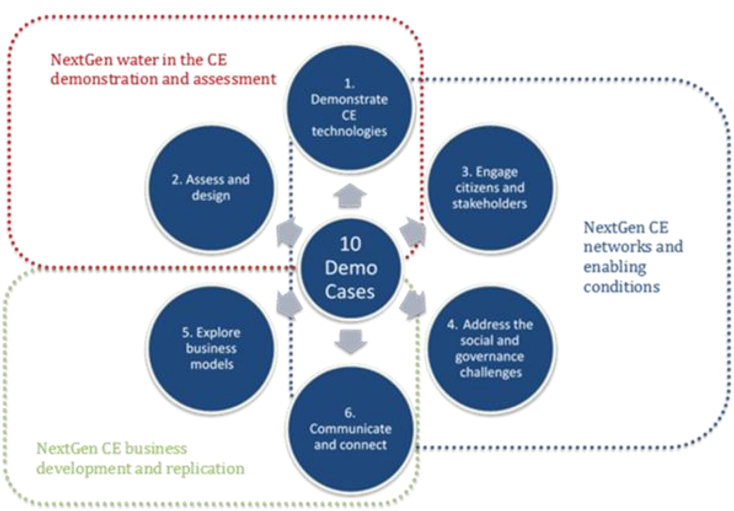

Figure 1: Structure of NextGen

Figure 2: NextGen demo case

Demo cases

Table 1.1 provides an overview of the circular water solutions demonstrated at the demo cases. The CE intervention of each demo case is specified through the water, energy and material nexus, coloured with blue (water), green (material) and yellow (energy). The specific circular water solutions vary considerably between demo cases, going from e.g. demonstrating one technology within a water treatment plant to solutions connected to other sectors in the CE.

WPs

NextGen takes an integrated approach addressing technological, environmental, economic, business, participatory, societal, regulatory and governance aspects of the circular water economy. This is exemplified in the following Work Packages (WPs):

- WP1: Demonstrate Technologies & Systems for Water in the CE
- WP2: Assess Technologies and Design Systems for Water in the CE
- WP3: Involve and Engage Citizens and Other Stakeholders
- WP4: Address the Social and Governance Challenges to Uptake of Circular Solutions for Water Systems and Services
- WP5: Explore New Business Models and Support Market Creation
- WP6: Communicate, Connect, Create Synergies and Support Learning
- WP7: Project Management
- WP8: Ethics requirements

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Table 1.1: NextGen circular water solutions

Demo Case	Technologies		
#1 Braunschweig (DE)	Two-stage digestion and sludge hydrolysis	Nutrient recovery: Ammonia stripping; Struvite precipitation	
#2 Costa Brava Region (ES)	Multi-purpose water reclamation and reuse	Membrane filtration with regenerated RO membranes	
#3 Westland Region (NL)	Alternative water sources, i.e. Aquifer Storage & Recovery for horticulture	HT-ATES: high temperature aquifer thermal energy storage	Material brokerage
#4 Altenrhein (CH)	Ammonia membrane stripping	P-recovery by thermochemical treatment of sludge	Granulated activated carbon via pyrolysis
#5 Spernal (UK)	Multi-stream anaerobic MBR for decentralized water reuse	Energy recovery from AnMBR	Nutrient recovery from AnMBR via adsorption and ion exchange
#6 La Trappe (NL)	Metabolic Network Reactor to produce fit-for-purpose water	Protein production in Bio-Makery	
#7 Gotland (SE)	Rainwater harvesting and decentralized membrane filtration	Energy efficient reclamation of wastewater	
#8 Athens Urban Tree Nursey (EL)	Sewer Mining mobile wastewater treatment for decentralized reuse applications	Heat recovery from MBR	Nutrient recovery for urban agriculture
#9 Filton Airfield (UK)	Integrated drainage system for urban water reuse	Heat recovery from sewer	Eco-sanitation systems with nutrients recovery
#10 Timisoara (RO)	Sludge management with production of by-products and/or energy	Reuse of effluent for urban, industrial and agricultural applications	

** blue = water, yellow = energy, green = materials*

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1.3 Outline of report

All results of the NextGen activities at the demo cases and the WPs are reported in 42 Deliverables, see Annex B. These Deliverables are also published at the project website: https://nextgenwater.eu/

To ensure the continued use 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 developed by NextGen, to which other projects such as ULTIMATE (GA N° 869318) and B-WaterSmart (GA N° 869474) will add their results: Water Europe Marketplace.

In this *D7.5 Synergies report* an extensive summary of the main results and outcomes of the NextGen project is presented:

- Chapter 2 presents the main results from the WPs.
- Chapter 3 presents the main outcomes from NextGen, i.e. impact, exploitation potential, policy relevance, key messages.
- Annex C presents the main findings from the technology demonstrations at the ten demo cases.

D7.6 Final Report will be centred on the key messages listed in section 3.4.

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2. Main results from NextGen

2.1 Circular Water Technology Demonstration

NextGen included ten demonstration sites across Europe providing evidence demonstrating the feasibility of innovative technological solutions. Through the demonstration sites, 26 potential technologies have been implemented and tested not only to close the water cycle, but also energy and materials cycles as depicted in Figure 2.1.

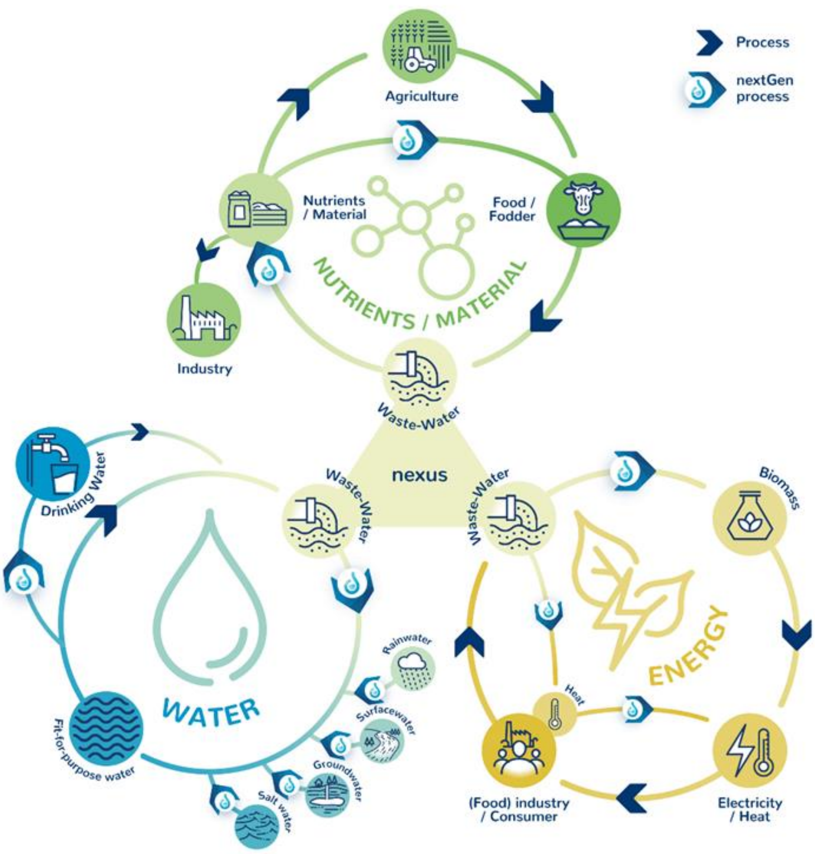

Figure 2.1. Infographic illustrating the water, energy, and materials cycles to be closed by circular economy solutions implemented during the NextGen project.

The demonstrated innovative solutions proved that technically we can transform wastewater into valuable and high-quality products such as reclaimed water, energy production, and/or recovered materials.

In the following sections, the obtained main results for each cycle are resumed. In Annex C, a summary of the technology demonstrations for each demo case is presented.

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Water

To close 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. The main results obtained are summarized in Table 2.1 in terms of potable water savings and the use of the produced reclaimed water.

Table 2.1. Summary of demonstrated innovative solutions for closing the water cycle. In grey, feasibility study on reclaimed water production from wastewater; in orange, advanced wastewater treatments; in green, rainwater harvesting studies; and in blue, aquifer storage systems.

Case study	Technology	Water use	Quantified impact
Timişoara	Feasibility study on reclaimed water production	Urban, industrial and agricultural use	Theoretical study; 10 800 m^3/h
Spernal	Anaerobic membrane bioreactor	Farming and industrial use	TRL 7; 500 m^3/d
Athens	Membrane bioreactor (sewer mining unit)	Urban irrigation and other non-potable use	TRL 8; 25 m^3/d
La Trappe	Metabolic network reactor + MELiSSA Microfiltration/reverse osmosis membranes	Bottle washing, aeroponics and aquaculture	TRL 7; 100 L/h
Costa Brava	Ultrafiltration + regenerated reverse osmosis membranes	Private use	TRL 7; 2 m^3/h
Gotland	Decentralized reverse osmosis membrane system	Indirect drinking water supply	TRL 7; 1.6 m^3/h
	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
Filton Airfield	Alternative water source (i.e., rainwater)	Toilet flushing and public irrigation	Theoretical study; 10 – 75 % of water savings per year
Westland	Aquifer storage and recovery	Horticulture irrigation	Theoretical study; aquifer rainwater storage: 4.8 Mm^3/y; 80 % reduction of net groundwater extraction

Energy

Three energy recovery practices were demonstrated to close the energy cycle: (1) heat recovery from wastewater and local reuse, (2) biogas production from sewage sludge, and (3) heat storage and recovery. In Table 2.2, the main results obtained from the tested CE solutions are presented in terms of the amount of energy (kWh/time) that can be obtained from the different sources, or the amount of biogas produced.

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Table 2.2. Summary of demonstrated innovative solutions for closing the energy cycle. In orange, heat recovery from wastewater and local reuse; in green, biogas production from sewage sludge; and in blue, heat storage and recovery systems.

Case study	Technology	Energy use	Quantified impact
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
Filton Airfield	Simulation-based study	Domestic use-space and water heating	41 m3/day; 38,788 kWh/year recovered (theoretical)
Braunschweig	Thermal hydrolysis and two-stage digestion	Reuse within the WWTP: Digestion, CHP and buildings	Feed with dry matter 10-13% of wet weight; Increase in biogas production: 20%
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 the two scenarios: 1.CHP-electricity and heat: 44 kWh/day and ~ 50kWh heat/d (assuming around 15% losses) 2. Biogas upgrading: 108 kWh/d
Westland	Aquifer thermal energy storage	Heating demand for horticulture	4200 MWh/y charged, and 3750 MWh/y discharged; Heat recovery factor: 0.89

Materials

To close the materials cycle, 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. Our work proved that it is technically 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. The main outcomes derived from these technical and physical demonstrations are summarized in Table 2.3.

Technological Evidence Base

A Technology Evidence Base (TEB) was developed and populated. This TEB includes information about the demonstrated circular economy solutions of the NextGen project and two other Horizon 2020 projects, ULTIMATE and B-WaterSmart. Apart of technologies, the TEB also houses case study specific results from all projects. The TEB aims provides a unified access point to results and allows easy access to relevant information needed for setting up a new circular economy scheme in the water sector.

The TEB is accessible via the Water Europe Marketplace (https://mp.watereurope.eu/), also developed within NextGen. For the TEB, the NextGen consortium developed and uploaded 26 technology factsheets (https://mp.watereurope.eu/teb/) and 10 case studies factsheets (https://mp.watereurope.eu/l/CaseStudy/) including their NextGen results.

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Table 2.3. Summary of demonstrated innovative solutions for closing the materials cycle. In orange, material recovery from sludge; in green, protein production; in blue, nitrogen removal and recovery; and in grey, phosphorus removal and/or recovery.

Case study	Technology	Material recovered	Quantified impact
Athens	Rapid composting bioreactor	Compost	TRL 7 → recovery: C: 60%, N:80%, P: 100%; 5 t compost/a; 600 PE: 1 t N/a & 0.34 t P/a
Timişoara	Pyrolysis	Pyrolysis gas, oil and char	TRL 4 → recovery: 18% gas, 63% char, 2% oil; 2.1 kg dried sludge/h; 400 000 PE: 3100 m³ gas/d
Altenrhein	Pyrolysis	Granular activated carbon	TRL 7 → recovery: 50% GAC, 50% gas, sieving losses; 1 kg dried sludge/h; Suitable as pre-treatment for conventional GAC filter
	Hollow fibre membrane contactor	Ammonium sulphate	TRL 8 → recovery: N: 75%; 8.5 m³ centrate/h; 305 000 PE: 66 t N/a
	Thermal treatment	PK fertiliser	TRL 8 → recovery: P: 90-100%; 50 kg dried sludge/h; 305 000 PE: 260 t P/a
La Trappe	Photobioreactor	Proteins as slow-release fertiliser	TRL 5-6 → recovery: COD: 38%, N: 20%, P: 25%; 60 L wastewater/d; Pilot: 276-575 kg dried biomass/a Successfully tested to grow microgreens
Braunschweig	Air stripping and scrubbing	Ammonium sulphate	TRL 9 → recovery: N: 85-97%; 7-19 m³ liquor/h; 380 000 PE: 175 t N/a
	CO2 stripping and precipitation	Struvite	TRL 9 → recovery: P: 80-97%; 7-19 m³ liquor/h; 380 000 PE: 37 t P/a & 17 tN/a
Spernal	Ion exchange and hollow fibre membrane contactor	Ammonium sulphate	TRL 6: recovery: N > 76%, IEX >80%, HFMC >95%; 1 m³ AnMBR effluent/d; Upscaling: 100 000 PE: 320 t N/a
	Ion exchange and precipitation	Hydroxyapatite	TRL 6 → recovery: P: > 72%; IEX >80%; precipitator >90%; 1 m³ AnMBR effluent/d ; 100 000 PE: 61 t P/a

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2.2 Technology Assessments

The economic and environmental performance of individual CE water technologies and associated risks has been assessed. The circular solutions are stress-tested, as it is important that they are sustainable at the system level.

Environmental assessment

Results of Life Cycle Assessment for six demo cases have shown 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, it depends on the specific situation at the site if these potentials can be realized, or if CE leads to a higher environmental footprint at least in some areas of environmental concern.

Water reuse can be a good alternative to other energy-intensive options for water supply such as seawater desalination or water import over long distance, which then leads to overall savings in energy demand and related greenhouse gas (GHG) emissions for water supply. For energy recovery from wastewater or sludge, it is important to assess the holistic energy balance of the systems rather than focusing only on the additional biogas or heat recovered. In principle, anaerobic treatment of wastewater yields the potential for energy-neutral or even energy-positive wastewater schemes with low carbon footprint (Figure 2.1). Nutrient recovery from wastewater is affected by trade-offs between chemical and energy intensive "high-tech" processes and the need for pure and high-quality products. "Low tech" nutrient recovery with sludge or compost yields more benefits in energy and GHG balance, but product quality can be minor.

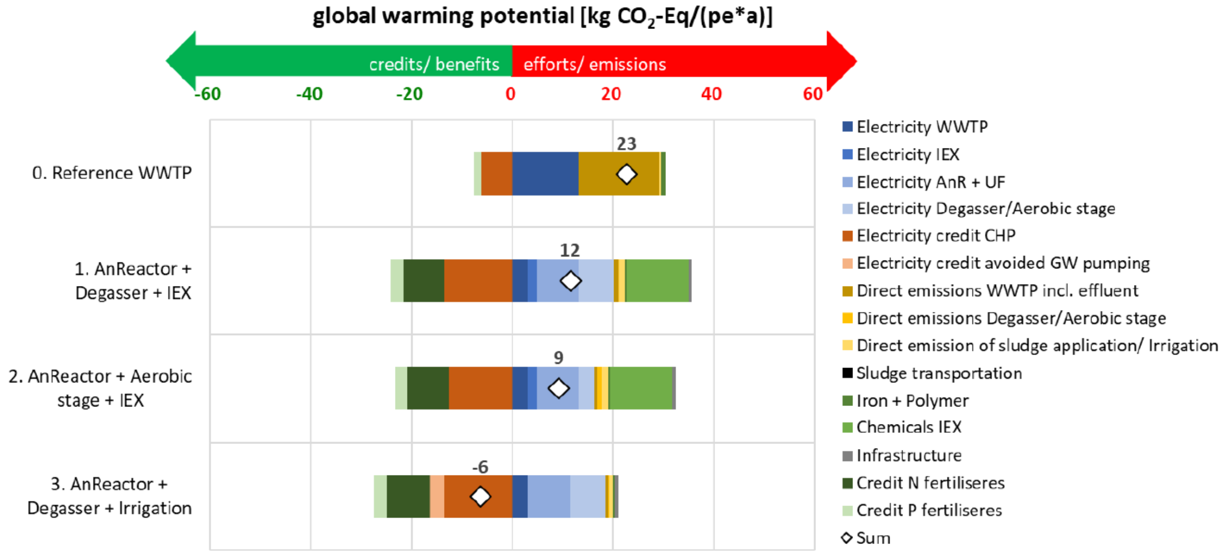

Figure 2.1: Reduction in life cycle CO2e emissions with anaerobic treatment of municipal wastewater combined with nutrient recovery via ion exchange (Spernal demo case)

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Quantitative microbial risk assessment (QMRA) of water reuse in five case studies demonstrated the potential for safe implementation of water reuse applications using almost all tested treatment configurations. However, the results also identify the need for local validation monitoring: in the absence of additional local information, default values for treatment performance generally result in wide ranges of potential removal of pathogens, which are less informative. The results are consistent with the approach proposed by the new EU water reuse regulation. The QMRA tool used in NextGen is freely available for use in an online version.

In quantitative chemical risk assessment (QCRA) of four CE products, it was shown that no unacceptable or critical risk for ecosystems or humans originate from the application of nutrient products recovered in CE concepts. Few substances have been identified which could pose a potential risk to ecosystems (PFOS, mercury), and more analytical data is required to assess these substances more precisely in the recovered products. In addition, analytical limits of detection and also available knowledge of toxicity and environmental behavior for PFOS have to be improved to make sure that risk from these substances to ecosystems is acceptable.

Economic assessment

In the NextGen Life Cycle Costing (LCC), additional cost for 19 circular scenarios located at six of the demo sites were calculated from the perspective of the operators. The NextGen Cost Effectiveness Analysis (CEA) put life cycle costs of a scenario in relation to its environmental benefits. Our main observations:

- All assessed demo cases involve wastewater treatment. **Small-size local solutions** have a higher specific treatment cost**.** However, it can save cost for energy and infrastructure for transport. Also, organisational aspects might favour local solutions.
- For water reuse, three cases show lower cost than other available water sources. A total of seven scenarios involves **upgrading of the wastewater to enable reuse** and three can supply water **at a lower specific price** than the sampled drinking water supplies.
- For P recovery from sludge, one scenario was cost effective compared to mineral P. However, except for this PK-fertilizer production of Altenrhein, the implementation of NextGen **nutrient recovery systems** is not profitable at this stage, as the revenues from fertilisers are lower than the OPEX and CAPEX of the recovery. Therefore, the motivation for nutrient recovery is often to fulfil legal requirements (e.g. phosphorus recovery) or reducing nutrient loads in a WWTP at its capacity limits.
- NextGen scenarios target circularity and most also reduce climate emissions in doing so. In three scenarios for anaerobic wastewater treatment, OPEX for CO_2eq reduction are lower than the current certificate price of 100 EUR/t CO_2eq. However, overall only few are cost effective with regards to climate mitigation, i.e. below the price of CO_2-certificates.

The assessed scenarios are examples for new water techniques valid in their geographical, regulatory and current market context. They can serve as an orientation to identify options

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(Figure 2.2), which can be further detailed in feasibility studies for other sites and complemented with experimental data as necessary.

The cost effectiveness of the assessed technologies will change as they are further developed and reach market maturity just as environmental policy and requirements will change. System services such as water reuse, climate mitigation or reduction of pollution are not profitable. Thus, a cost assessment indicates the most cost-effective solution in a given policy framework.

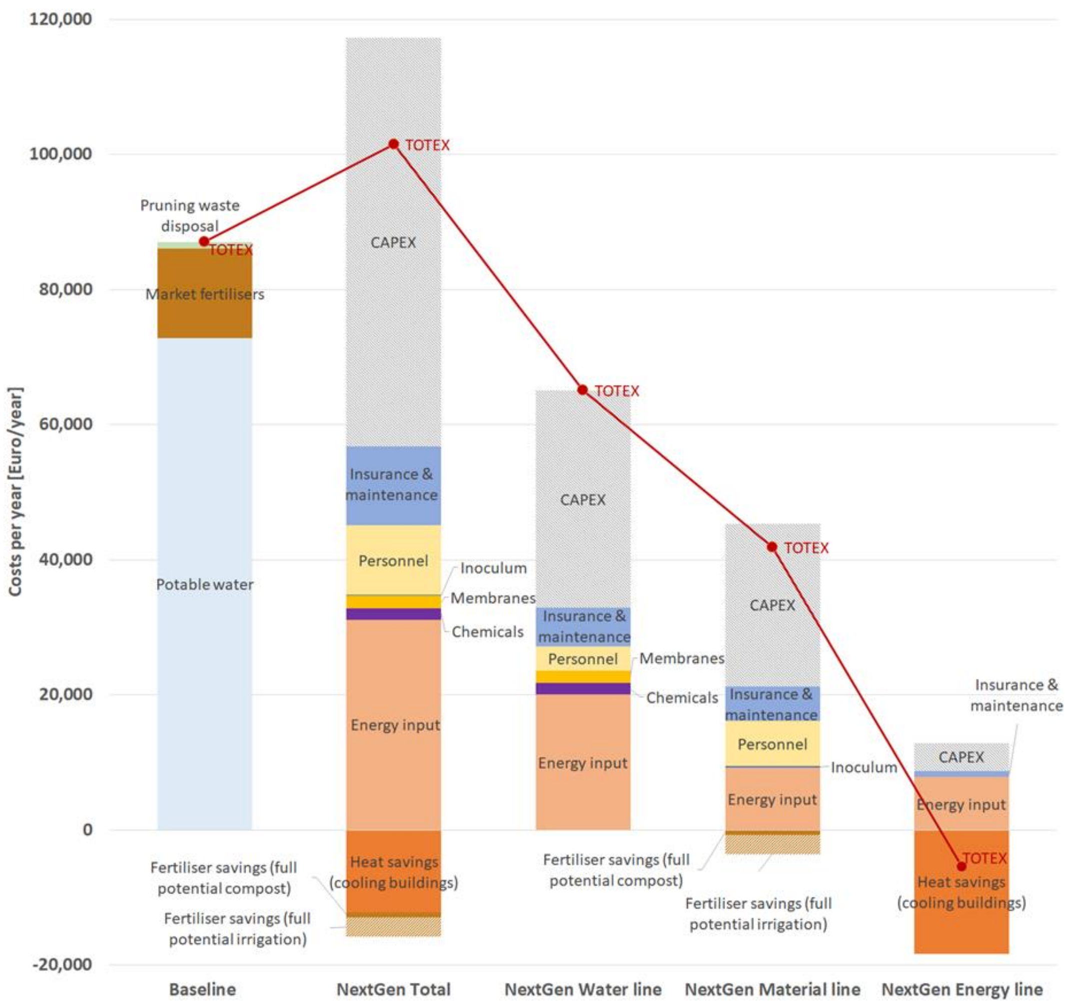

Figure 2.2: Assessment showing cost of three technologies and their combination compared to baseline in the Athens demo case

Re-design and stress test

To improve the cycle's overall performance, the selected systems have been modelled to evaluate, compare and optimise the configuration of the system.

The ***Hydroptim*** Decision Support System (DSS) models and optimizes the cost of the water networks, and its uses in short and long term planification. It also evaluates cost in "what-if" studies. Cost is evaluated as energy costs, the main OPEX of water networks. Environmental cost was developed as an option during NextGen to evaluate also alternative sources of water.

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Hydroptim was demonstrated in cases studies with regional water management (Costa Brava, Westland).

UWOT (Urban Water Optioneering Tool) is a simulation based DSS simulating the urban water cycle by modelling individual water uses and technologies/options for managing them and assessing their combined effects at multiple scales, starting from the household level and progressing up to neighbourhood, regional and entire city level. UWOT was demonstrated at demo cases with city/neighbourhood water management (Athens, Filton Airfield, Westland).

The main conclusions specific to the case of Westland Region are that UWOT is able to provide a holistic view on both urban and horticulture domains of the regional system, treating it as a unified urban-regional water system, where different redesigns that target either (or both) subsystems can be quantitatively compared and stress-tested against uncertain possible futures. See Figure 2.3 for an example of a scenario with water saving / reuse for households and waterbanking for greenhouses modelled by UWOT for Westland.

We found that **the more ambitious redesign strategies** investigated **were also the most efficient** in increasing the **resilience** of the regional system. These strategies include sustainable rainwater aquifer storage and WWTP effluent reuse for horticulture and demand reduction measures with decentralized rainwater harvesting and greywater recycling for the urban area, reusing and recycling water locally and securing the system against future uncertainty. Simpler strategies that target one domain, while not efficient in multiple aspects of the water cycle, are still significantly beneficial to the region and lead to a more resilient future. In contrast, the cost continuing linear water management would be high, requiring significant investment in increasing central supply.

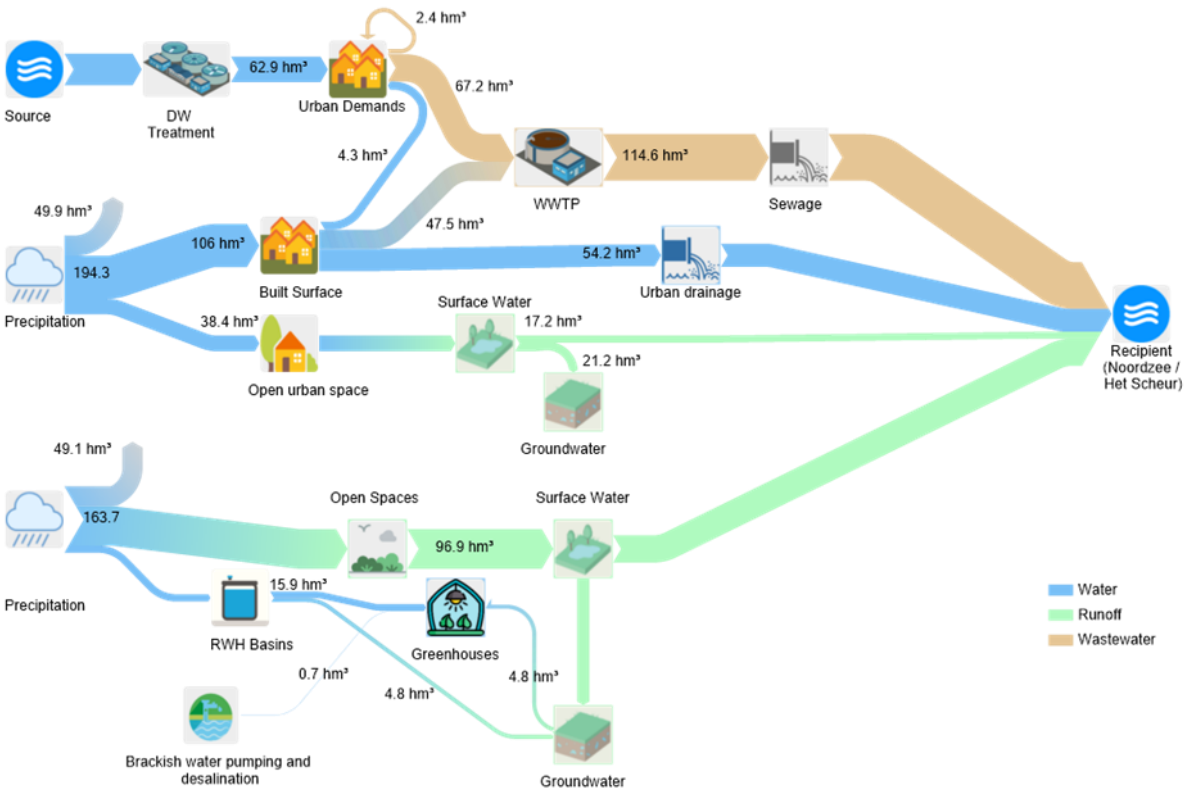

Figure 2.3: Example of a redesign scenario modelled by UWOT for Westland Region

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2.3 Stakeholder Engagement

CoPs

The transition to a circular water economy requires the active engagement from relevant stakeholders. This engagement can be organised through Communities of Practice (CoPs) in which circular water solutions are discussed in their institutional context. At the ten NextGen demo sites, stakeholders regularly met in CoP workshops to: (a) set a common vision; (b) identify opportunities for further closing the water, energy and materials cycle; (c) reflect on the economic and environmental benefits; (d) address governance barriers; and (e) discuss upscaling of the demonstrated technologies.

In total, 37 CoP meetings have been organised, in which more than 300 people participated. An important success factor was the wide representation of the different stakeholder groups in the CoPs: water industry experts (15%), technology providers (9%), research organisations (21%), end users (22%), representatives of other sectors, such as agriculture, industry, energy (11%) and policy / governance actors (22%).

As part of NextGen, **a novel evaluation framework** has been developed that assesses CoPs in terms of their effectiveness in enabling social learning and achieving the CoP- and project-objectives (Figure 2.4).

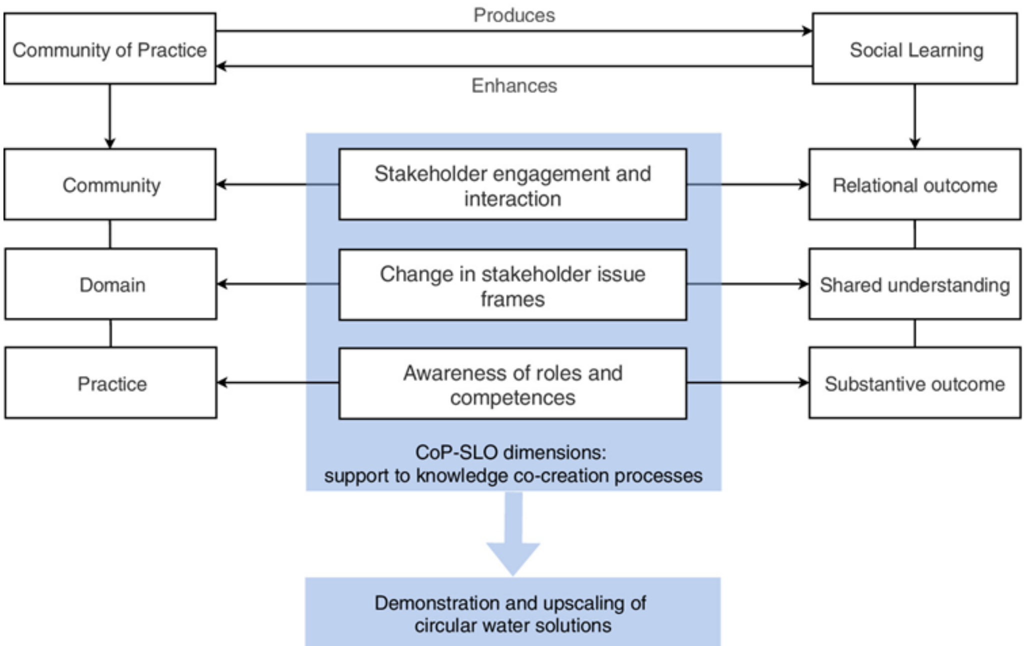

Figure 2.4: CoP evaluation framework for social learning outcomes.

The evaluation results from the participants of the CoP meetings show very good scores, average between 4.2 and 4.5 (from 1.0 lowest to 5.0 highest) for all factors that contribute to social learning and hence engagement achieved through the CoPs.

The CoP meetings were organised in such a way that there was scope for open dialogue through all six key success factors:

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- Organizational aspects of the meeting: prior information, materials, duration.
- Atmosphere: presentation clarity, behaviour, communication.
- Stakeholder representation and engagement: opportunities to discuss, conflict resolution, inclusion of ideas.
- Convergence towards shared perspective: topic inclusion, stakeholder understanding, moderation
- Identification of new opportunities and challenges: time to reflect, clarity of outcomes.
- Generation of knowledge: matching expectations, increase of awareness on circularity.

We concluded that CoPs positively contributed to engagement and interaction of stakeholders, change in stakeholders issue frames, and stakeholder awareness of their own role and competence and of those of other members.

AR and SG

In addition to public outreach activities at the demo cases, citizen engagement has been enhanced by virtual visualisation platforms such as a Augmented Reality app (AR) and Serious Games (SG) in which the general public can experience circular water solutions.

The NextGen Augmented Reality app CirculAR (https://nextgen.iccs.gr/) was built and demonstrated for the demo cases Athens and Gotland (Figure 2.5) plus a virtual demo case that enables other sites to adopt a sustainable and circular water use regardless of their location. The AR applications aim to drastically increase the learning value of the showcases by making visible 'hidden' or 'intangible' elements of the water cycle and demonstrated solutions to visitors.

Figure 2.5: View from the CirculAR app at the Athens sewer mining bioreactor (left) and the drainage ditches of Gotland (right)

The AR app for the virtual city provides principles of the CE in the water cycle to bring to the attention of the users, fun facts and information to engage them, as well as best practices to comfort to a circular water use. The audience of such content range from students to researchers, and citizens of a municipality.

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A survey of 127 citizens, showed that CirculAR positively fosters citizen engagement for new and rather unknown topics such CE. In total, 86% gained a better understanding of CE principles and ability to apply them in real life. The AR is more appealing to novice practitioners. Younger people and citizens more used to IT technologies, reach high engagement and motivation towards CE through CirculAR.

The NextGen Serious Game (http://nextgen-serious-game.s3-website.eu-central-1.amazonaws.com/nextgen-choice.html) aims to allow participants to understand circular economy for water by observing interactions between different components in the urban water cycle and energy and their effects on flows of water and energy and material recovery. Participants can range from the general public to policy makers, to water, energy, and environment specialists. The SG has been developed in three different versions: a virtual generic urban catchment area referred to as “Toy Town” (Figure 2.6), the demo case for Athens that focuses on sewer mining, and the demo case for Costa Brava that focuses on a Mediterranean touristic setting with aquifer management and desalinisation.

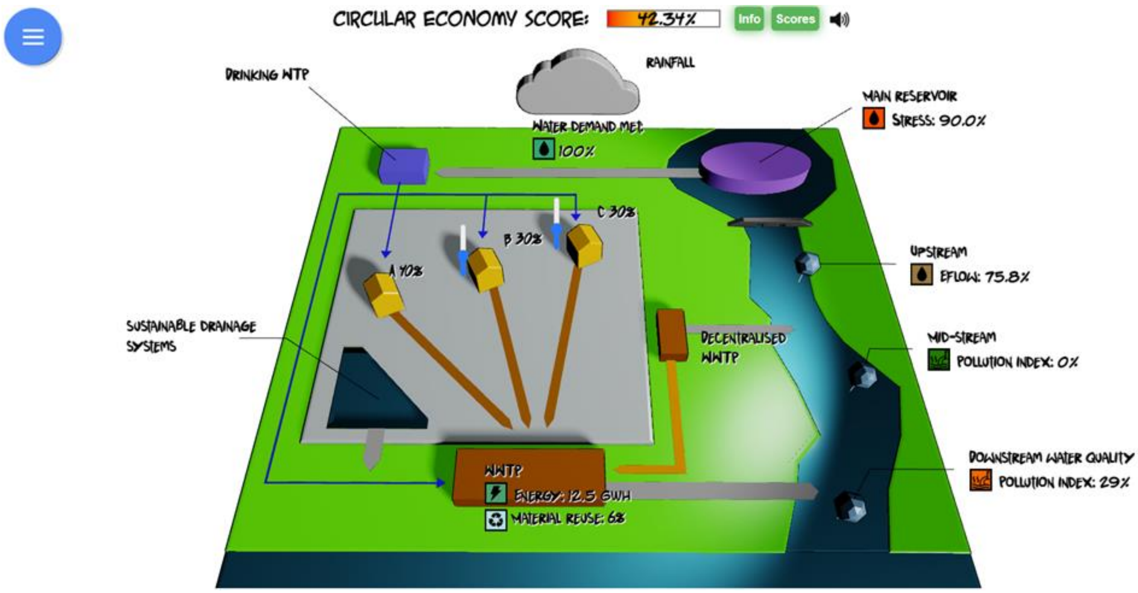

Figure 2.6: Screenshot of the NextGen Serious Game (Toy Town).

Several physical and online game-playing events took place where participants were able to take the appropriate measures to maximize Circular Economy for water when a virtual catchment was exposed to challenging scenarios, e.g., lower rainfalls and population growth. The players included students, environmental scientists, engineers, policy makers, and members of the public. The NextGen Serious Game was successfully used as a teaching tool in student classrooms. Participants who joined the supervised training sessions were on average 26% more likely to answer correctly technical questions related to a circular urban water cycle.

Results from the NextGen Serious Game and CirculAR, that benefit people to experience circular water solutions, show the high potential of increasing public understanding and acceptance.

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2.4 Social Acceptability and Regulations

Public acceptance

Public acceptance is of utmost importance as the people are end-users of water and its recovered resources. In a quantitative study, we present the findings from three large-scale surveys of the general public in the UK (n=1028), the Netherlands (n=751) and Spain (n=800). The surveys focused on two circular solutions utilised in the water and wastewater sector – the use of recycled water for drinking purposes, and the use of recovered nutrients to grow food. The aim of the surveys was to investigate acceptance of these solutions from the perspective of three dependent variables: a) willingness to consume, b) support for, c) willingness to pay more for: recycled drinking water and food grown with recovered nutrients.

Overall results show that support for the two circular solutions appeared high in all three countries. The proportions of respondents who supported or strongly supported the use of recycled water for drinking were 67% (UK), 73% (ES) and 75% (NL). The proportions of respondents who supported or strongly supported the use of recovered nutrients to grow food were 74% (UK), 75% (NL) and 85% (ES). Also of interest is the relatively low percentage of people not agreeing with these rather extreme (i.e. drinking recycled water) circular solutions.

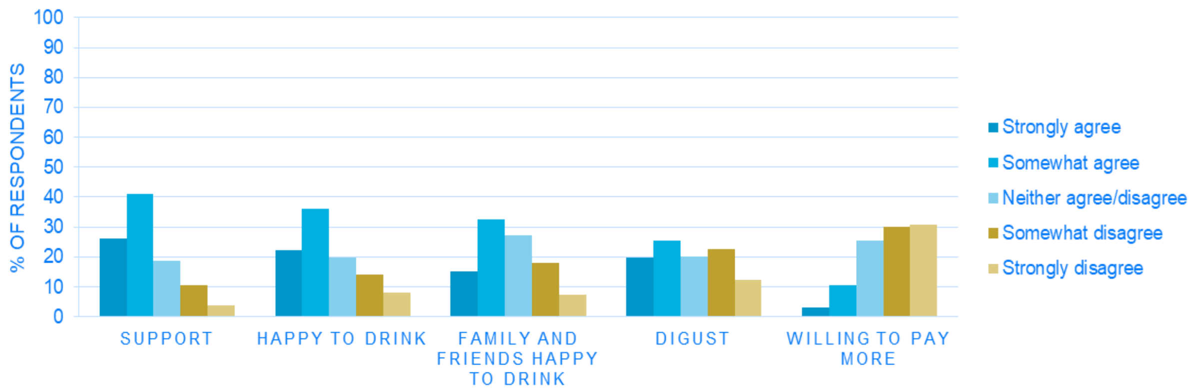

Figure 2.7: Survey results on acceptance of recycled drinking water from U.K. (n=1028)

There were significant differences in responses to water recycling and responses to recovered nutrients, with the latter having higher acceptance in all three countries and across all dependent variables. The key conclusions from our analysis are that, for two of the dependent variables (support and willingness to consume), social norms and emotions emerged as two of the strongest predictors, for both circular products and in all three countries. This means that respondents in all three countries are more likely to support the circular solutions, and consume the products from them, if they feel positively towards them, and if they believe that others would do the same. Social norms had the strongest role in predicting willingness to pay more for food grown with recovered nutrients, while knowledge had a stronger role in predicting willingness to pay more for recycled water.

In a qualitative study, the work takes a holistic perspective based on the concept of legitimacy, to present a comprehensive view of societal perceptions towards circular solutions. We interviewed key stakeholders associated to two selected demo cases (Gotland and La Trappe).

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Results showed that the selected demo cases stimulated the four legitimacy dimensions (cognitive, pragmatic, normative and regulative) and engaged in different legitimisation strategies for their adopted circular solutions. The La Trappe demo case lacked the incorporation of public consultation and involvement which weakened the pragmatic dimension of legitimacy, while its focus towards visitors and customers strengthened the branding aspect of the pragmatic dimension. The Gotland demo case was found to evolve within a highly engaged and influential community (pragmatic and normative dimensions of legitimacy) although shortcomings were found regarding the comprehensibility of the circular solutions (cognitive dimension of legitimacy).

Regulatory framework

The transition to circular water systems and services requires supportive policies and regulations. We explored the policy and regulatory landscape to identify the enablers for, and barriers to, adopting circular value chains in the water and wastewater sector, up-scaling solutions and transferring technologies to other geographic areas. We concentrated on four aspects of policy and regulation for circularity for the sector: 1) the implementation of the new Water Reuse Regulation for large-scale water reuse schemes; 2) small-scale circular schemes (notably rainwater and greywater recycling) and their incorporation into planning and building frameworks; 3) the regulatory landscape surrounding the recovery of materials and energy from water and wastewater systems; and 4) the development of innovative financing options for circular solutions.

Methods included reviews of literature as well as primary data collection (via questionnaires and interviews) with a selection of NextGen demo cases. Findings identified a number of persistent challenges that could be hindering the wider uptake of circular solutions in the sector, as well as a number of opportunities to create a more supportive regulatory landscape. For the Water Reuse Regulation, there is concern over how compliance will be supported within each Member State's national structures, and how uncertainty over compliance could hinder further development in the sector. For planning and building regulatory frameworks, there is wide variation between member states, and an overall regulatory gap, around how smaller-scale (building-scale) circular solutions are addressed. For energy and materials recovery, the growing interest around these technologies amongst utilities in the European sector has not yet been matched with the emergence of a coherent policy and regulatory framework around technology adoption and bringing products to market. For financing, there is clear opportunity for circular solutions to become part of the ESG investment landscape, and to become the focal point for more public-private partnerships.

Based on these findings we proposed several recommendations, which are intended to inform the national legislative frameworks of Member States, as well as European legislation (with reference to the UWWTD, as well as other associated directives). These recommendations were detailed in a NextGen Policy Brief and are briefly included below.

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Table 2.4: Policy conditions enabling or hindering the recovery of resources at the NextGen demo cases

	What's helpful	What's hindering	What's needed
Energy (biogas, heat)	• Carbon neutrality targets	• Disappearing policy incentives and feed-in tariffs • Shift away from burning fossil fuels (biogas)	• Clearer pathways for the water sector to support a hydrogen economy
Biosolids	• Quality certification	• Concern that land application may become stricter or prohibited (fate of micro-pollutants) • Land availability (diffuse pollution prevention)	

Other nutrient products (e.g. struvite, ammonia)
Other material products (e.g. cellulose)
	• Carbon neutrality targets
	  • Process benefits
	  • Carbon footprint of alternatives
	• Fertiliser Regulation (potentially)
	• Stricter discharge limits (Zero Pollution)
		• Complex and burdensome process for end-of-waste status
		• Risk for utilities and technology developers
			• Simplified route to end-of-waste
			  • Clearer exemption from waste legislation?
			• Better governance mechanisms for sharing risk

Non-potable water (e.g. fertigation)	• Consistent quality standards between countries (Water Quality Regulation) • Stricter discharge limits (Zero Pollution)	• Insufficient granularity for different purposes • Challenging monitoring and reporting requirements • Concern that land application may become stricter or prohibited (fate of micro-pollutants)	• Support for 'fit-for-purpose' approach • Risk management approach

Recommendations for national governments of Member States:

- Support active stakeholder engagement in Water Reuse Risk Management Plans
- Adjust tariff systems to better support circular solutions
- Explicitly incorporate small-scale circular solutions in planning and building frameworks
- Support efficient risk sharing in contracting for Public-Private-Partnership arrangements

Recommendations for EU policy and legislation:

- Improve alignment between directives and incentivise circularity
- Include the water / wastewater sector in energy efficiency and renewable energy
    - but improve alignment with environmental ambitions
- Adopt the water fit-for-purpose principle
- Improve clarity and transparency for the Water Reuse Regulation
    - clarify responsibilities for water reuse permit allocation
    - support a public evidence database of reuse schemes
    - create a master list of water quality parameters
- Create simpler and less costly routes to market for recovered resources
    - create dedicated End-of-Waste routes for products recovered from wastewater and sludge
    - ensure that End-of-Waste status can be recognised across Member States
- Ensure that circular water systems can be targeted with ESG / green financing.

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Roadmap to support uptake

Applying CE principles to the water sector requires a holistic vision and an integrated approach. Technological, economic, socio-cultural and regulatory conditions determine the shift from a linear to a circular water economy. At the ten NextGen demo cases, we identified 12 key drivers, 20 key barriers and 20 key support measures to the upscaling of solutions.

Table 2.5: Main support instruments that will enable the further implementation / upscaling of the circular water technology (CWT) at the ten demo cases

Technology instruments	Economic instruments
R&D / Proof of Concept	Tariff structures that favor reuse and tax water use
Public evidence database of circular water schemes	Subsidies for secondary materials and recycled water
Master list of water quality parameters and risk database	Investment grants (ESG / green bonds)
Quality control and monitoring procedures	Risk sharing in PPP arrangements
Environmental Technology Verification	Market place to connect producers and consumers
Socio-cultural instruments	**Regulatory instruments**
Information sharing and public outreach campaigns	Stricter environmental regulations
Active stakeholder engagement	Improved clarity of Water Reuse Regulation
Socio-political work to push CWT	Planning and building frameworks adapted for small-scale CWT
Independent review panels	Simplified process for achieving end-of-waste status
Positive framing of reused water / recovered product	Better aligned EU directives (with circularity emphasis)

For an effective transition, the efforts coming from all four instruments is needed, starting simultaneously now. Thus, a roadmap for the EU wide uptake of circular water solutions would have to consist of a comprehensive ‘package’ of enabling instruments at short-term, 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.

Establishing such a comprehensive package of instruments would speed up the implementation of different types of circular water technologies. This would result in a roadmap with the EU wide uptake of *Reduce of resources* on a short term (2020-2025), *Reuse / recycle water* on a short to medium term (2020-2030), and the *Recovery of products* on a medium term (2025-2030). Although *Rethink the CE water system* will most likely take a long-term perspective (2030-2050), strategies that legitimise circular water technologies in society and the economy have to be employed already now.

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2.5 Circular Business Models

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. A circular business canvas has been established and 23 circular value chains from the 10 NextGen demo cases have been identified. For selected circular solutions, a market assessment and business plans for spinoffs have been developed.

Circular Value Chains

Different options of circular business model innovation have been explored, and we developed an *EcoCanvas* circular business model tool that includes economic, legal, environmental and social challenges. The developed tool to analyse circularity and/or business models of companies or water treatment sites has been successfully tested in e.g. La Trappe demo case and seems to be effective gathering information enough to describe several circularity aspects of an entity/circular site. From a business model point of view, the performance of a water circular system is much easier to reach if the water treatment systems are combined with supporting technologies to recover and treat waste streams. In addition, it has a positive impact from the environmental point of view as well thanks to the decrease of produced waste. The overall results show that the tool can give useful information of the circularity of a site at different levels and opportunities to improve it.

Complementary to this work, the assessment of NextGen value chains brought forward additional data on how NextGen innovative solutions can be economically sustainable beyond the project. The 10 demo cases were analysed to highlight good practices and foster mutual learning among case studies. As one of the findings, it is important to develop products with high added value that can become profitable by establishing themselves in niches, on a small scale.

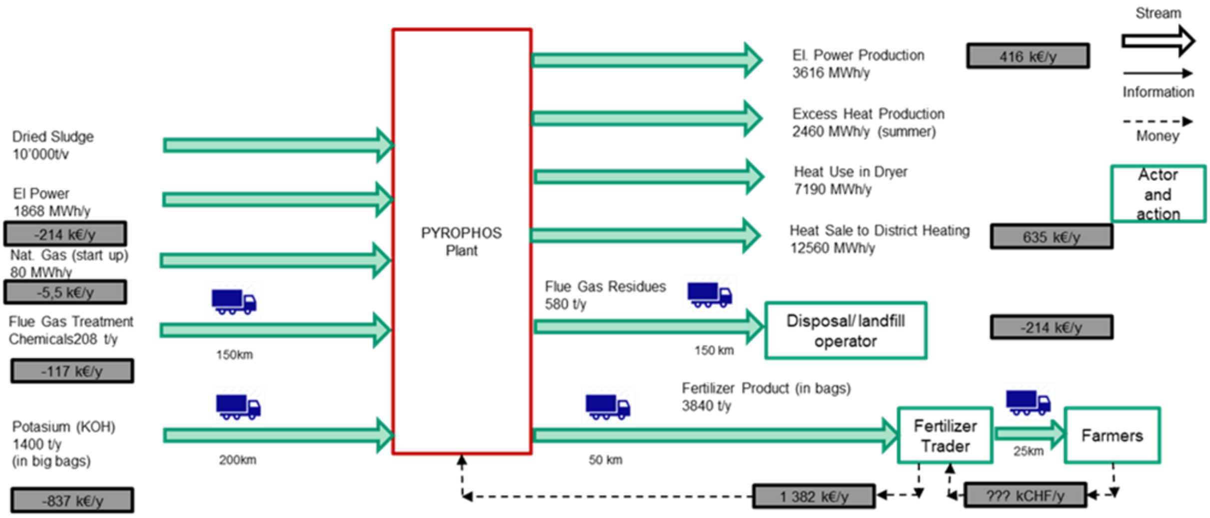

Figure 2.8: The PK-fertiliser value chain of Altenrhein demo case

This work also allowed to propose recommendations for policymakers and circular project leaders to solve challenges and difficulties hindering circular value chain implementation and development. These included *inter alia* the need for economic incentives to promote circular solutions, promote resource recovery with an obligation to 'blend', price management of

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regenerated water. Innovative financing instruments are needed to overcome market difficulties, such as government subsidies (e.g. green bonds) or incentive regulation (e.g. carbon tax).

Further activities related to business model development targeted NextGen technical solutions with the study of three high potential spinoffs that will be pursuing their activities beyond the project (see also Section 3.2):

- NEWater Source start-up: a spinoff for water reuse in France, building on the sewer mining concept of the Athens demo case
- A joint cooperation for upcycling water residuals, such as recovered calcite, between Strane and AquaMinerals
- The online Marketplace promoting water reuse solutions among stakeholders, by Water Europe (*this option will not be pursued as a new spinoff but as a collaboration between Water Europe and an existing spinoff*).

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 NextGen CE Marketplace is an online, flexible, and adaptable system to search for or share information about innovative and transformational circular economy solutions and systems, to connect with other stakeholders and to explore best practices around resource use in the domains Water, Energy and Materials.

The **CE Marketplace** consists of:

- **Technology Evidence Base**: a comprehensive database of technology factsheets (taxonomy of 34 CE technologies) and 10 NextGen case study factsheets with results from the technology demonstrations at the demo cases
- **The Toolkit**: 11 innovative products supporting the CE, such as environmental and economic assessment tools, modelling and redesign tools
- **The Interactive Platform**: 73 stakeholders, networking functionality, recommender system with personalized information, advanced search mechanism on all data categories.

The Marketplace will be further developed under the ULTIMATE and B-WaterSmart projects, through which the knowledge base will be further enhanced with case studies, products and technologies. The Marketplace will be integrated into the workflow of Water Europe, supporting events and face-to-face meetings, and expanding the CE professionals' network.

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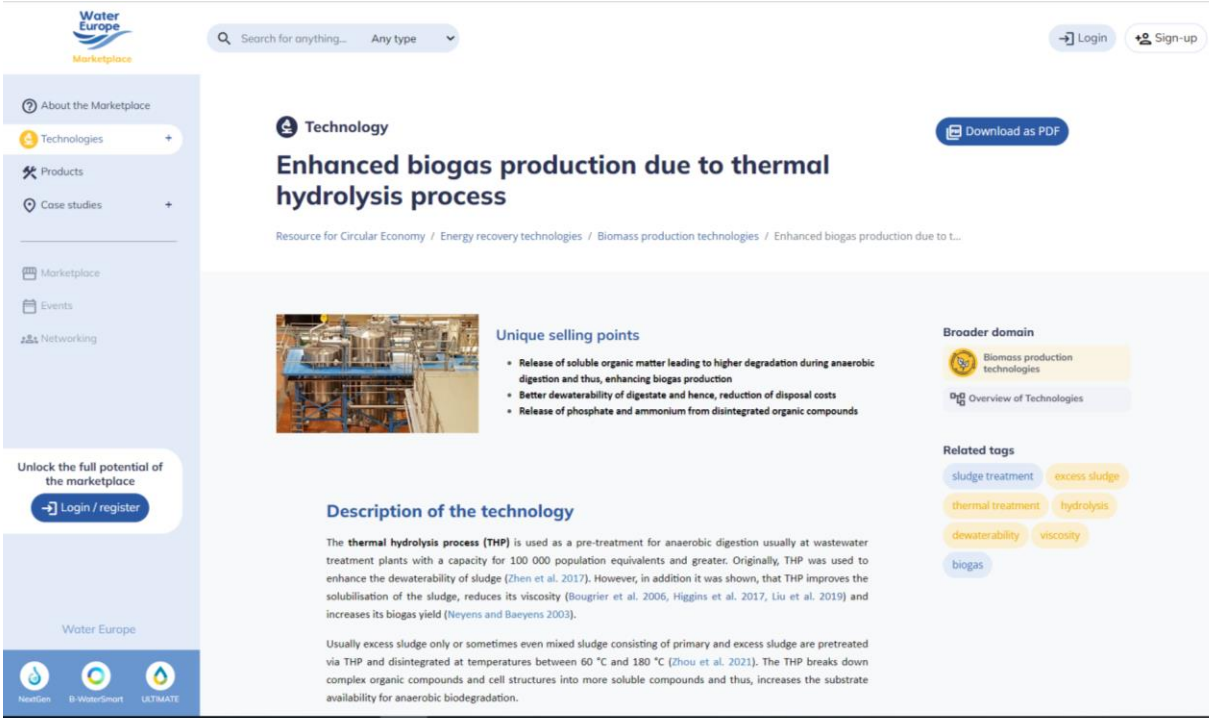

Figure 2.9: Example page on the online Water Europe Marketplace of an energy technology demonstrated at the Braunschweig demo case

2.6 Communication and Outreach

NextGen created impact through communications actions that built trust and accelerated solutions for the Water Circular Economy. We took pockets of proven performance and shared the knowledge and tools to make these new innovations mainstream. Our mission was to do this across multiple online and in-person channels using a creative mix of compelling and coherent content.

Profiling Demo cases

We profiled the 10 demo cases and portrayed their activities and results in many creative ways. Each demo case has a separate page in our website, profiling their main activities, key data and if the solutions are connected to water, energy, and/or materials. The demo cases also each have separate presentations and videos that are on the website, SlideShare and on our YouTube channel. We also developed posters that are available for download on our website. We further created a series of blog post for each demo case. Those were posted and used as content for our social media. That increased traffic to the website (over 1200 clicks through), via demo-case posts. They brought 3x more people to our website than normal posts. Finally, we also had 6 of our demo cases profiled in news outlets and La Trappe, Westland Region and Costa Brava Region featured in our Videos News Releases, with news broadcasted in Catalunya, Switzerland and internationally with Euronews.

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Figure 2.10: La Trappe monk and NextGen partner De Dommel interviewed for Euronews

Compelling content to distribute

We constantly developed new and creative content to populate our social media, website and push for external publishers. We generated multiple video interviews and articles, be it in our own websites or independent. We published over 70 articles in our website, collaborating successfully with partners. We further interviewed 14 different specialists on video throughout the project duration, explaining and exploring different angles from our activities, from policy to citizen engagement. A Flyer and postcard were developed and distributed on opportunities for in-person communication such as events and conferences. We also created 4 roll-ups to be used by our partners in different events, using the NextGen's logo and identity. In the end of the project, we produced a final infographic that will contain the main results from NextGen in an easy to grasp and creative way for fast distribution.

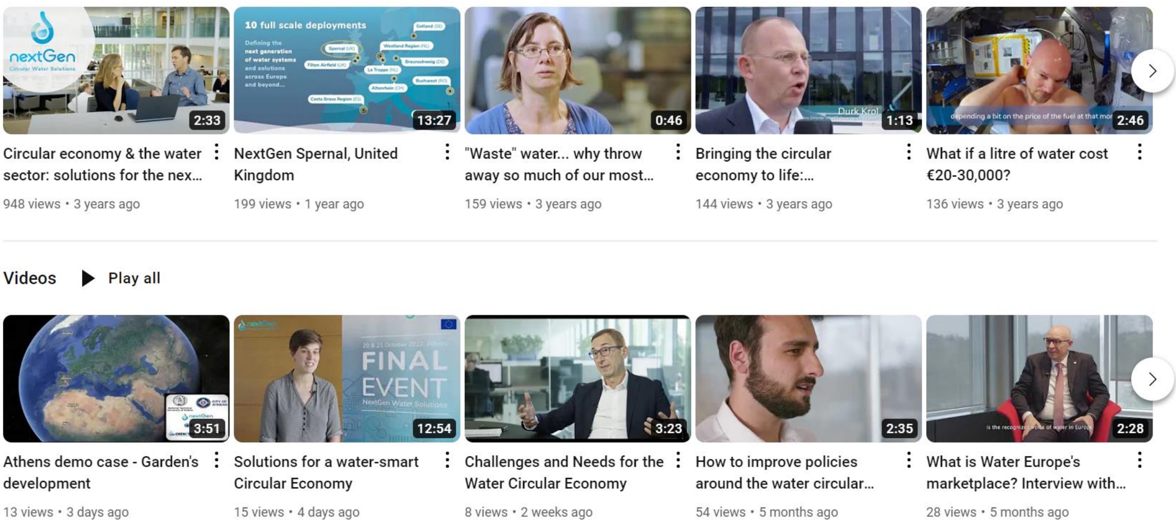

Figure 2.11: Some of the videos and interviews published on YouTube by NextGen

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Website
Our website https://nextgenwater.eu/ has been quite successful. It has received 573 monthly visits, far surpassing our initial KPI of 400 visits/month, with an average visit duration of 2 min and 7 sec. (which indicates that people stay in the webpage and are interested in its content).

In the last year alone, the website was accessed by 17535 users. In comparison to other project's websites managed by ESCI, NextGen has continuously ranked between the 5 most accessed sites. The website was mostly accessed through search engines such as Google and social media. 118 countries accessed it, being the countries with the most access the UK and US, and with our international partner countries, India and China being part of the 15 countries with most users of our website.

Social media
Also our social media activities reached high numbers of followers and views:

Media	KPI	reached	posts/videos	impressions	engagements
LinkedIn	280 followers	1550 followers	386 post	76,6K	2227
Twitter	500 followers	1600 followers	652 posts	44,2K	1016
YouTube	3000 views	3600 views	34 videos		
Instagram	-	264 followers	68 posts		

Presentations at and exposure around Water Europe events to collaborate with EU policy
Water Europe is a member-based multistakeholder platform. The membership and activities of the organisation have continuously grown and evolved in line with its ambition to represent the whole value-chain of water and achieve a European Water-Smart Society. As a partner, NextGen has took advantage of the organisation network potential and has participated in at least four of its events. At the Water Market Europe 2022 event in Brussels we launched our Water Europe Marketplace and promote its future use. We also created videos and interviews to advertise the Market Place and NextGen's actions on Policy reviews. We further promoted connections with the Ultimate Project that will continue to develop and promote the Marketplace.

Through the development and publishing of our five Policy Briefs / Position Papers, we aim on communicating our findings and recommendations to the EU policy makers regarding Water Management, Wastewater Treatment and Circular Economy:

- H2020 Water Innovations for Sustainable Impacts in Industries and Utilities (2019)
- Water in the Circular Economy policy development (2021)
- Nutrient Management: Create a water-smart action plan for closing nutrients cycles (2022)
- Solutions for a Water-Smart, circular and resilient UWWTD and SSD (2022)
- Stakeholder engagement in the Circular Water Economy (2022)

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International collaboration (connecting with partners in India, China, and Korea)

During the project, several exchanges took place in various events, forums, and network meetings, with our partners in South-Korea (KIST); India (TSWO), and China (JIEI). Those networking events led among others to a Watershare webinar called: NextGen Circular Water Solutions Across the Globe. In this online webinar our associated partners in India, China and South Korea presented their work in their countries. We complemented it with interviews with each researcher that were published on our website and social media. Finally, we assessed the replication potential of NextGen solutions in India, China, and Korea, with AnMBR (Spernal) as a suitable technology and our Serious Game for awareness raising.

Figure 2.12: Exchange event in China with NextGen partners JIEI and IVL

Academic outreach

The NextGen project developed important research which was published in approximately 40 papers in scientific journals under open access licenses. The following are our 10 peer reviewed articles published so far; there are three more under review:

- Liakopoulou, A., Makropoulos, C., Nikolopoulos, D., Monokrousou, K. & Karakatsanis, G. (2020). An urban water simulation model for the design, testing and economic viability assessment of distributed water management systems for a circular economy. *Environmental Sciences Proceedings* 2 (1), 14.
- Fulgenzi, A., Brouwer, S., Baker, K., & Frijns, J. (2020) Communities of practice at the center of circular water solutions. *Wires Water* 7, e1450.
- Kim, J.E., XiangTeh, E., Humphrey, D. & Hofman, J. (2021). Optimal storage sizing for indoor arena rainwater harvesting: Hydraulic simulation and economic assessment. *Journal of Environmental Management* 280, 111847
- Plevri, A., Monokrousou, K., Makropoulos, C., Lioumis, C., Tazes, N., Lytras, E., Samios, S., Katsouras, G. & Tsalas, N. (2021). Sewer Mining as a Distributed Intervention for Water-Energy-Materials in the Circular Economy Suitable for Dense Urban Environments: A Real World Demonstration in the City of Athens. *Water* 13 (19).
- Kim, J.E., Humphrey, D. & Hofman, J. (2021). Evaluation of harvesting urban water resources for sustainable water management: Case study in Filton Airfield, UK. *Journal of Environmental Management* 322, 116049

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- Morseletto, P., Mooren, C.E. & Munaretto, S. (2022) Circular Economy of Water: Definition, Strategies and Challenges. *Circular Economy and Sustainability*
- Katika T., Karaseitanidis I., Tsiakou D., Makropoulos C., & Amditis A., (2022) Augmented Reality (AR) Supporting Citizen Engagement in Circular Economy, *Circular Economy and Sustainability* 2, 1077–1104
- Afghani, N., Hamhaber, J. & Frijns, J. (2022) An Integrated Assessment Framework for Transition to Water Circularity. *Sustainability* 14(14), 8533
- Yahya Qtaishat, Y., Hofman, J. & Adeyeye, K. (2022). Circular Water Economy in the EU: Findings from Demonstrator Projects. *Clean Technologies* 4(3), 865-892
- Makropoulos, C., Garriga, S.C., Kleyböcker, A., Sockeel, C.-X., Rios, C.P., Smith, H. & Frijns, J. (2022). A water-sensitive circular economy and the nexus concept. In: Handbook on the Water-Energy-Food Nexus. Edward Elgar Publishing, pp. 113–131.
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- Evans, B., Khoury, M., Vamvakeridou-Lyroudia, L., Chen, O., Mustafee, N., Chen, A.S., Djordjevic, S. & Savic, D., A new modelling testbed to Demonstrate the Circular Economy in the Context of Water, Journal of Cleaner Production (*submitted*)
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To further disseminate, key insights from these papers became articles in our website, thoroughly posted on social media and sometimes interviews.

During the project, all partners and demonstration sites capitalised on available outreach opportunities at events for professional, academic and public audiences. Local, national and international events, being present and presenting our project in over 50 events, such as the IWA World Water Conference (Tokyo 2018, Copenhagen 2022), Amsterdam International Water Week (2019, 2021), and Singapore International Water Week (2022).

Local stakeholders were also reached. Each demo case had their own events (at least one) with end users, industry, farmers and much more with Communities of Practice. They were extremely useful in getting people to be more involved throughout the Project in most demo cases. Further, local and online events were created to present the Serious Game and Augmented Reality app for users such as the MSc students of Water Engineering at NTUA.

Experience from selected demo cases have been communicated in flyers on a diversity of topics: policy, regulations and acceptance (Braunschweig); socio-technical performance (Costa Brava); business (Westland); water-energy (Spernal); pollution reduction (Altenrhein); opportunities for industry (La Trappe); and communication with stakeholders and citizens (Gotland).

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3. Main outcomes from NextGen

3.1 Impact

Objectives reached

NextGen brought together a critical mass of people, technologies, business innovations and solutions and challenged embedded thinking and practices in the water sector. The project mobilised a strong partnership of water companies, industry, specialised SMEs, applied research institutes, technology platforms, city and regional authorities and leveraged an impressive portfolio of past research and innovation projects to test and demonstrate its innovations and then utilised its unique access to European and global networks to ensure wide dissemination and a clear pathway to its multiple impacts.

We provided new evidence and demonstrated the feasibility of innovative technological solutions supporting a transition towards a more Circular Economy-based Water Sector. In particular, technologies and solutions that close the water, energy and materials cycles were implemented in all 10 demonstration cases and were thoroughly assessed in terms of performance, cost efficiency and optimisation potential under a wide range of "stress scenarios" to assess their resilience; we adopted a holistic approach towards stakeholder engagement to ensure wider uptake of circular water solutions and worked towards identifying and addressing key social and governance barriers. Importantly we also developed and launched new business models to promote the 'economy' part our circular economy propositions. Our multi-angle approach has its clear benefits in building an overall picture of CE in water landscape.

The table below, presents our Strategic Objectives (as included in the DOA) and briefly discusses how we achieved them.

Table 3.1: NextGen Strategic Objectives (SOs) and level of achievement at the end of the project.

SOs	Initial target of SOs	Level of Achievement of SOs
SO1	Develop and demonstrate innovative technological, business and governance solutions supporting a CE approach to water, energy and materials within the water cycle, at a range of scales (from city to region and river basin) and provide end-users with a portfolio of next generation systems and services as well as the tools to transfer/upscale them (KPIs: 1, 2, 3, 16 and 17)	26 innovative circular technological solutions were developed and deployed in 10 European demonstration sites that can act as a starting point to be adapted at different scales (from local to city to regional) and be replicated worldwide. End-users were provided with a balanced portfolio of sustainable next generation circular systems, tools and methodologies, which were thoroughly studied and illustrated through the NextGen TEB and the CE Marketplace. Several business opportunities were explored namely: 23 value chains were analysed in the case studies, including business potential, resulting in 2 spinoffs. A series of governance and policy recommendations were also provided through the analysis of challenges and opportunities of the regulatory framework.

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SO2	Demonstrate the benefit of these solutions in reducing current water, energy and raw materials consumption and increasing self-sufficiency at regional and river basin scales and assess their potential future benefits using novel systemic assessment methods and tools. Reduction in greenhouse gas emissions will be quantified to lead the way to carbon neutral water services, in accordance with the COP21 Paris agreement and Sustainable Development Goal (SDG) 12 (KPIs: 4 & 5)	By transforming waste into high quality products, we saved water, energy and raw materials increasing autonomy and self-sufficiency e.g. rainwater harvesting and greywater reuse contributed to reducing freshwater consumption. NextGen demonstrated and further developed technologies that are in line with the ambitions of the European Green Deal its Action Plan for Circular Economy to strongly reduce the EU greenhouse gas emissions, to provide clean water, maintain healthy soil, make industry resilient and produce cleaner energy. Reduction in greenhouse gas emissions was achieved in 3 scenarios for anaerobic wastewater treatment, where OPEX for CO2e reduction are lower than current certificate price of 100 EUR/t CO2eq., in accordance with the COP21 Paris agreement and Sustainable Development Goal (SDG) 12, e.g. the AnMBR technology has also lower OPEX and better CO2 balance than SoA for treating municipal wastewater.
SO3	Demonstrate how next generation water systems and services can directly or indirectly benefit other relevant economic sectors of the CE (incl. food/agriculture, land development and construction, environmental protection services, chemical industry etc.) (KPI 6, 16 and 17)	A demonstration of how the CE water systems can benefit other relevant economy sectors was performed through the Serious Game for Water in the CE, allowing "players" to visualise and understand the circular approach to water management, by providing advice, role-playing and negotiations functionalities between stakeholders of the water value chain (agriculture, tourism, construction industry, and land and property developers).
SO4	Mitigate barriers to the upscaling of solutions by providing evidence-based knowledge on policy challenges, social acceptability, novel governance arrangements, regulations and performance benchmarking, outlining the whole range of enabling framework conditions for the transition to a CE in the water sector. (KPI 7)	The project successfully identified 12 key drivers, 20 key barriers and 20 key mitigation measures to the upscaling of solutions, and outlined policy challenges, social acceptability, novel governance arrangements, as well as enabling governance framework conditions for the transition to a CE in the water sector, including a roadmap for a broader transition in the EU.
SO5	Increase citizen involvement in and satisfaction with water in CE by engaging citizens and other stakeholders in the innovation chain itself, through Communities of Practice and Living Labs, made even more engaging through Serious Games (SG) and Augmented Reality (AR) tools. This is expected to enhance acceptance, and also improve the quality of the outcomes, which is in line with a guiding principle of Horizon 2020: the notion of Responsible Research and Innovation (RRI). (KPI 8)	The active involvement from key stakeholders and citizens within the created engaging environment was achieved through systematic Communities of Practice (CoPs) meetings in a co-creation and co-acting spirit, Serious Games (SG) and Augmented Reality apps, in which the users visualise and literally experience options, scenarios, opportunities and challenges in a circular approach to water management. Thus, societal acceptability on sustainable water circular solutions was enhanced improving the quality of project results in line with the approach of Responsible Research and Innovation (RRI).
SO6	Create new market opportunities and smart businesses for the water sector as a central actor in the CE and demonstrate how these can be used to sustain smart growth, close investment gaps in	23 value chains were analysed in the case studies, including business potential. 2 spin-offs have passed the go/no-go decision creating new jobs. An open innovation CE ecosystem around water

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	infrastructure, improve existing and create new services, while at the same time, help achieve SDGs 12 and 6. (KPIs: 9, 10, 11 & 12). Help nurture an open innovation CE ecosystem around water through an online Marketplace, providing standard (e.g. matchmaking, selling, brokerage) as well as advanced functions (e.g. innovation funding and spin-off launching) in close collaboration with, and providing support to, existing networks such as the Water Europe, allowing them to also link up with other industries within a CE context (KPIs: 13, 14 and 15).	(CE Marketplace) has been nurtured with: a) a Toolbox of products, tools and methodologies supporting the CE; b) a technology evidence base and c) a repository of case study factsheets, d) a recommender system and e) a networking component. The CE Marketplace, *adopted by Water Europe to ensure long-term sustainability*, has been proven to serve as a meeting place for stakeholders of the circular economy as well as to be engaging to users in a tangible and active way, allowing them to seek solutions or promote innovative scientific and technical solutions in the fields of water, energy, and materials.

Impact achieved

We demonstrated 26 innovative circular solutions and technologies, deployed and tested in 10 diverse, European demonstration sites, inspiring others around Europe and worldwide. These solutions proved able to produce high quality “products” in terms of water but also in terms of energy and materials and 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. These solutions can act as a starting point to be adapted at different scales and be replicated worldwide.

Detailed assessments were carried out for existing and new technologies providing sound evidence of environmental and economic performance and clearly identifying risks and improvement option. Life Cycle Assessments were performed for six case studies, Quantitative Microbial Risk Assessments (QMRA) of water reuse at five case studies and Life Cycle Costing (LCC) were calculated at six of the demo cases from the perspective of the operators. Furthermore, two water system simulation tools, HydrOptim and Urban Water Optioneering Tool (UWOT), have been used in four demo cases, to model the whole water cycle (modified by our circular economy interventions) and to evaluate, compare and optimise the configuration of these solutions to improve the cycle’s overall performance.

This directly links our work to **climate mitigation and adaptation** at several scales (from local to city to regional) as well as clear technical, environmental, and financial feasibility assessments to underpin these solutions and ensure further uptake. But we also took a step further towards exploitation: we launched two spin-offs to fully pursue the potential of several of our solutions in the real world. The value chains on which these initiatives are based, were informed by the results from the demo case and the combined work on institutional, socio-economic and market gaps and requirements.

The project also deployed ‘**circular’ consultation procedures** for citizens and stakeholders to energise and engage a wide range of actors in the design and assessment of the NextGen solutions. Communities of Practice (CoPs) were organised in all 10 demo cases, through which stakeholders were engaged in a productive way and through this engagement they became ambassadors for NextGen’s circular solutions. To further support citizen engagement, an Augmented Reality App (AR) and a Serious Game were also developed to visualise and (virtually) experience circular water aspects and solutions.

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Our focus on the “economy” part of Circular Economy is also evidenced by the development and deployment of a CE Marketplace, adopted by Water Europe to ensure long-term sustainability. The Marketplace brings together technology providers and problem owners who would like to turn their linear processes to circular, as well as scientists, research institutes, enterprises, investors, and other interested parties and aspires to be a launchpad for CE co-creation and uptake.

In the table below we briefly discuss and provide quantifiable evidence for the projects actual impacts, mapped onto the Expected Impacts (EI) defined in the DOA.

Table 3.2. NextGen Expected Impacts (EI) and level of achievement at the end of the project.

EIs	Initial target of EIs	Level of Achievement of EI
EI1	Significant reduction of the current water and energy consumption at regional and/or river basin scale [See **SO1 and SO2** targets]	Within the project we observed: ▪ Freshwater savings: 0.1 – 20 m^3/h of reclaimed water produced; 10 – 80 % savings of annual drinking water production (see D1.3) ▪ Heat recovery: COP heating = 4.0 5.12; 44 - 100 kWh/d recovered; heat recovery factor: 0.89 (see D1.4) ▪ Materials recovery rate: 50% GAC, 18% gas, 75-97 % N, 72–100% P. The replication potential of the implemented approaches in the demo sites was proven in systems such as rainwater harvesting, wastewater reuse, sewer mining and urban ASR, sludge management, nutrients and energy recovery and the use of renewable energy.
EI2	Interconnectivity between the water system and other economic and social sectors [See **SO3** targets]	An element of interconnectivity was provided through the Serious Game tool for Water in the CE, allowing citizens to visualise and understand the circular approach to water management, and also supporting advice provision, role-playing and negotiations between stakeholders of the water value chain (agriculture, tourism, construction industry, and land and property developers).
EI3	Increased public involvement in water management [See **SO5** targets]	A dedicated and targeted action plan for engaging stakeholders and citizens in the water value chain was implemented throughout the project, via the innovative approach of CoPs in which more than 300 people participated showing a wide representation of the different stakeholder groups: water industry experts (15%), technology providers (9%), research organisations (21%), end users (22%), representatives of other sectors, such as agriculture, industry, energy (11%) and policy / governance actors (22%). To further support citizen engagement, Augmented Reality App (AR) and Serious Game tools were developed to visualise and (virtually) experience circular water aspects and solutions.
EI4	Increased citizen satisfaction with water services [See **SO5** targets]	To raise citizens’ awareness about barriers, challenges, solutions and benefits from technologies and services, 37 well-structured CoP meetings were organised, creating a secure engaging environment, in which the participants were able to share their knowledge and experiences, express reservations or concerns and provide further potential and insights on the developed technologies and tools. Furthermore, NextGen SG and AR application helped citizens visualise ‘hidden’ or ‘intangible’ parts of the circle and hence enabled deeper understanding and holistic perception of the bigger picture of CE-based solutions and methods.
EI5	Replication of new business models in other areas and replication of models for synergies between appropriate funding instruments at regional, national or European level	23 value chains were analysed in the case studies, including business potential. 2 spin-offs have passed the go/no-go decision creating new jobs. An open innovation CE ecosystem around water (CE Marketplace), adopted by Water Europe to ensure long-term sustainability, brings together technology providers and problem owners who would like to turn their linear processes to circular, and to operationalise new business models, incl. spinoffs, empowered through innovation/green deals, identifying

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	[See **SO6** targets]	suitable funding schemes (as well as synergies between them) and finding collaborators. At the end of the project, the CE Marketplace hosts datasets and factsheets for 24 products, 52 technologies and domains of the CE, 22 case studies, 141 publications, 77 organisations, 200 tags and 15 events. Further, NextGen demonstrated the viability of the proposed business models based on a CE approach at local to city to regional scales.
EI6	Closing of the infrastructure and investment gap in the water service sector [See **SO6** targets]	NextGen provides a whole value chain, CE approach demonstrated at large scales, bridging the gap between investment needs and available funds by creating new services together with end users and making them accessible to the wider European Market and innovation ecosystem. Specifically NextGen combined 26 circular water solutions with 7 tested tools actively involving stakeholders and interested parties. By demonstrating these solutions in the real world and sharing these experiences widely, NextGen contributes to a building of trust between investors (public and private) and innovators. On the matter of cost (as a barrier to uptake) and related market potential, we chose technologies that have a cost similar to or even lower than the cost of state of the art, as only such technologies have a chance of being implemented in the near future (if not required by legislation). The cost competitiveness of these technologies has also the positive effect that circularity was achieved “for free”, i.e. without (much) additional cost. An assessment of market potential for these technologies at the EU level is in D7.5.
EI7	Creation of new markets in the short and medium term [See **SO6** targets]	NextGen supported and pursued the creation of spinoffs (2 spinoffs have passed the go/no-go decision) for initiating and implemented water-efficient CE services, bringing new market dynamics to circular solutions. Further, through the CE Marketplace interested parties across the water value chain can share experiences, interact and collaborate. At the end of the project more than 2100 people have visited in the CE Marketplace and over 100 people have become active users. 9 of them have identified themselves as problem owners, 46 as solution providers and 4 as investors. As this system is integrated into the WE Marketplace, it is reasonable to assume that this new market shall continue to grow and shall be enhanced with new updated material and engage more active users. Thus, the project tangibly contributed to further promoting several innovative solutions to become viable business opportunities at regional, national or European level both at the short and at the medium term.
EI8	Providing evidence-based knowledge regarding the enabling framework conditions that facilitate a broader transition to a CE in the EU. [See **SO4** targets]	NextGen provided new insights and a wide range of evidence-based knowledge from the analysis, assessment and modelling of the demo sites, fostering transformative change across cities and sectors of society towards a broader transition to a CE in the EU. All solutions (case studies, tools and assessments) are included in a well-structured and scientifically documented manner in the TEB and CE Marketplace enabling dissemination of insights and fostering an EU-wide dialogue.
EI9	Implementing the Sustainable Development Goals (SDGs), and especially SDG 12 'Ensure sustainable consumption and production patterns' and SDG 6 'Ensure availability and sustainable management of water and sanitation for all', as well as the conclusions of the COP21 Paris Agreement. [See **SO2** targets for SGD12 and COP21, and **SO6** targets for SDG6]	To contribute to SDG 12 and SDG 6, as well as support conclusions of the COP21 Paris Agreement, NextGen built and expanded further on the experiences accumulated through the implemented interventions and their assessments in line with the ambitions of the EU Strategy on Adaptation to Climate Change and the European Green Deal policy framework, to foster transformative change and ensure availability and sustainable management of water and sanitation for all.

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During the project the following **tangible results** were achieved:

- 26 technologies and solutions have been implemented and tested in the 10 NextGen demo sites in 8 different countries in Europe.
- 5 tools were developed or used and tested in selected demo cases studies: QMRA, QCRA, LCA, Hydroptim, UWOT and 2 more were used in crosscutting activities: The Augmented Reality app and the Serious Game.
- 21 assessments (LCA, LCC, QMRA, QCRA) were carried out in selected demo cases
- 37 Communities of Practice (CoPs) were organised at the 10 demo cases, in which more than 300 people participated.
- 60 local and national policy/governance actors/institutions were targeted by CoP meetings at the demo sites.
- The NextGen Serious Game engaged more than 40 students increasing their understanding of circular solutions, by visualising and experiencing them in a 'safe' playful environment.
- The NextGen Augmented Reality app (CirculAR) was used by 127 citizens increasing the awareness of the public for circular water solutions and their potential.
- 2,579 citizens were outreached through the societal acceptability survey.
- 12 key drivers, 20 key barriers and 20 key mitigation measures to the upscaling of solutions were identified at the demo cases.
- 5 policy briefs and position papers were produced: 3 of which co-authored with other CE projects and 2 discussed with EU policy makers (within Water Europe workshops).
- 23 circular value chains were analysed at the demo cases.
- 2 spin-offs have been launched.
- The NextGen MP (termed the "WE Marketplace") has gained over 2100 new members, 132 of which have formally registered to take advantage of the platform's capabilities.
- Approximately 40 papers published in scientific journals under open access licenses, ensuring wide dissemination of NextGen's knowledge to the European Research Area.
- 17 international meetings, engaging with more than 400 international key stakeholders; 80 events participation and organization (conferences, workshops, fair trades, etc.).
- 324 communications open to public, 573 monthly visits to the project website, around 1500 followers in Twitter and LinkedIn, 1100 posts in social and conventional media increasing the project's visibility, 7 flyers on a diversity of topics beyond the technical aspects, 34 videos illustrating NextGen approaches, solutions and insights have been published on our YouTube channel to ensure wider and more intuitive dissemination.

KPIs

By designing, assessing, and deploying innovative solutions for closing the water-energy-materials cycle, NextGen contributed directly to the key challenges of water scarcity, raw materials depletion, and climate change, based on a solid evidence base and strong local partnerships. Specific **quantified KPIs** are included in the following table.

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Table 3.3: NextGen's quantifiable KPIs and level of achievement at the end of the project

No.	KPIs	Quantifiable Target	Level of Achievement
1	Number of CE solutions demonstrated	10 demonstrated technologies	The target was achieved. Through the 10 demonstration sites, 26 CE solutions were tested and evaluated. Specifically, 10 solutions for closing the water cycle, 5 for closing the energy cycle, and 11 for closing the materials cycle. The CE solutions and the demonstration sites have also been presented as Technology Evidence Base (TEB) at the Marketplace hold by Water Europe.
2	Number of end-users involved	30	The target was achieved. More than 50 entities and end-users were involved involved through CoP meetings or beneficiaries of the recovered resources like municipalities or private users. These stakeholders were distributed among the 10 demonstration sites. Dissemination activities and workshops helped to increase the awareness, understanding and interest of implementing of CE solutions in the water sector within the local and targeted stakeholders.
3	Number of tools deployed and tested	4	The target was achieved. Seven tools were used and tested in selected demo cases studies: QMRA, QCRA, LCA, Hydroptim, UWOT and as crosscutting activites (Augmented Reality, Serious game).
4	Reduction of freshwater, primary energy and raw materials	10-30% increase of water availability, alternative energy and raw material compared to baseline. For wastewater treatment and water reuse together the project will provide integrated concepts which allow > 90 % electricity self-supply for non-potable water.	The target was achieved. The monitored KPIs at each demonstration site showed that technically we can transform waste into high quality products. These resources can then be translated into savings of freshwater (i.e., drinking water production), energy and raw materials. As a general overview, we observed: ▪ Freshwater savings: 0.1 – 20 m^3/h of reclaimed water produced; 10 – 80 % savings of annual drinking water production ▪ Heat recovery: coefficient of performance heating = 4.0- 5.12; 44 - 100 kWh/d recovered; heat recovery factor: 0.89 ▪ Materials recovery rate: 50% GAC, 18% gas, 75–97 % N, 72–100% P
5	OPEX and CAPEX per to of CO2 reduction, per to of nutrient or per volume of water	10 technologies/ solutions better than the baseline.	Target partly achieved: 7 scenarios better than baseline. In 3 scenarios for anaerobic wastewater treatment, OPEX for CO2e reduction are lower than current certificate price of 100 EUR/t CO_2eq. For P recovery from sludge, one scenario was cost effective compared to mineral P. For water reuse, 3 cases show lower cost than other available water sources. Other CE approaches were not economically competitive at current prices for products from the linear economy.

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No.	KPIs	Quantifiable Target	Level of Achievement
6	Cross-sectoral value generated in EUR (Value of recovered water, materials (e.g. fertilizers) and energy to be utilized in different sectors)	Potential of €100M/year shown	The target was achieved. Value of recovered resources in EU wide implementation was estimated for selected technologies. The value exceeds €100M for water, energy and also for nutrients.
7	Number of identified key barriers and demonstrated mitigation options	10	The target was achieved. We have identified at the ten NextGen demo cases 12 key drivers, 20 key barriers and 20 key mitigation measures to the upscaling of solutions, and outlined the enabling governance framework conditions for the transition to a CE in the water sector, including a roadmap for a broader transition in the EU.
8	Number of direct citizen involvements (e.g. through the living labs, SG, AR, questionnaires etc.)	50000 overall in all the cases	The target was achieved. The total number of visitors to the demo cases was well above 150 000 (e.g. visitors to the La Trappe breweries). The public outreach activities at the demo cases reached 500 citizens. Public understanding and acceptance were increased by visualising and experiencing circular water solutions through Augmented Reality (127 citizens) and Serious Games (44 students). Our societal acceptability survey reached 2.579 citizens.
9	Number of new business options proposed	5	The target was achieved. 23 value chains were analysed in the case studies, including business potential.
10	Number of new spin-offs set-up	3	The target was achieved. 3 spin-offs have passed the go/no-go decision: - NEWater Source startup: a spinoff for water reuse in France - A joint cooperation for upcycling water residuals between Strane and Aquaminerals - The online marketplace promoting water reuse solutions among stakeholders (*the MP however will not be developed as a new spinoff but will be undertaken as a join cooperation between Water Europe and an existing spinoff by NTUA*).
11	Quantified job potential	>200 new long-term and qualified jobs	The target was not achieved. The number of direct and indirect jobs was not quantifiable at the end of the project. The value chain analysis did not provide enough data to assess this target. The spinoffs development have confirmed their potential with the creation of 8 jobs in total since the beginning of the project.
12	Cross-reference of water supply and purification in developing countries with NextGen technology environmental impact, OPEX and CAPEX	2 technologies suitable for SDG 6	The target was achieved with two suitable technologies. With the target to contribute to SDG 6 replication potential of NextGen solutions in India, China and South Korea was assessed (D6.4). Firstly, stakeholders showed interest and context showed potential for AnMBR as a suitable technology. AnMBR has also lower OPEX and better CO_2 balance than SoA for treating municipal wastewater. AnMBR is expected to perform even better for the more concentrated industrial wastewater. Secondly, the NextGen Serious Game has potential for awareness raising and thus supporting implementation of sustainable water supply, especially in South Korea. It should be noted that NextGen demonstrated technologies suited for developing countries, but

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No.	KPIs	Quantifiable Target	Level of Achievement
			not the simple and robust technologies suited for least developed countries.
13	MarketPlace: Publishing, supporting and producing/trading.	2 CE services and >=50 distinct datasets (including open data)	The target was achieved. A number of CE services have been developed and integrated into the WE Marketplace. Most notable, a) the Toolbox of products, tools and methodologies supporting the CE b) the technology evidence base and c) the repository of case study factsheets, d) the recommender system and e) the networking component. While the Marketplace is continuously updated, currently it hosts datasets and factsheets for 24 products, 52 technologies and domains of the CE, 22 case studies, 141 publications, 77 organisations, 200 tags and 15 events.
14	MarketPlace: Engaging in a tangible and active way users	>20 users from demandand/or the supply side (developers, start-ups, CE services providers)	The target was achieved with over 100 active users. Nine of them have identified themselves as problem owners, 46 as solution providers and four as investors. Many other stakeholders and professionals have also registered. The number of registered organisations is 77.
15	MarketPlace: Engaging citizens in the demo cases (distinct from general citizen involvement under KPI8)	>1000 citizens	The target was achieved. 2100 people had visited the NextGen marketplace until the end of the project and it is fair to assume that most of them accessed information from the nextGen demo cases.
16	Increase share of recovered chemical energy	Increase recovered energy by >20% compared to baseline	The target was achieved. Chemical energy was produced in the Braunschweig and in the Spernal demo cases, where on average the share of recovered chemical energy in the form of biogas was increased by a factor of 1.2 and 2.2, respectively.
17	Reduce heat losses	>50% for wastewater treatment and water reuse together	The target was achieved. Rainwater harvesting and greywater reuse contributed to reducing freshwater consumption. In addition, there was potential to recover low-grade heat and nutrients from wastewater in the Filton Airfield case.
18	Increase the decision-makers' awareness of the central role of water in the CE	Engage >50 decision makers at local, nationaland EU levels in project activities	The target was achieved. More than 60 local and national policy / governance actors were targeted by CoP meetings at the demo sites, where they are informed of NextGen solutions to promote the idea of circular water interventions as part of a broader water-aware policy to key authorities and legislation bodies. More than 50 European policy officers and stakeholders were/will be targeted by WE through different channels (eg. workshops [WPE], bilaterals [with the EC, member states' representatives], events [WIE], presentations [Danube Water Forum 2022]) to promote NextGen.
19	Support water in the CE policy development at the EU level	Produce at least 2 policy briefs/position papers (possibly in	The target was achieved. 5 policy briefs produced (3 with other CE projects) and 2 discussed with EU policy makers (WE workshops): 1. H2020 Water Innovations for Sustainable Impacts in Industries and Utilities (2019)

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No.	KPIs	Quantifiable Target	Level of Achievement
		collaboration with other CE projects) and deliver them to EU policy makers.	2. Water in the Circular Economy policy development (2021) 3. Nutrient Management: Create a Water-Smart Action Plan for Closing Nutrients Cycles (2022) 4. Solutions for a Water-Smart, circular and resilient UWWTD and SSD (2022) 5. Community of Practices: a tool for stakeholder involvement in complex technologies (2022) We also provided input to several EU policy reports e.g. on Energy efficient WWTP and Zero Pollution Action Plan, and WE will distribute the final report to EU policy makers.
20	Increase the visibility of the EU as a global CE leader	Expose project work and enage with >50 key international stakeholders also in consultation with APs	The target was achieved. The project has been presented at more than 17 international meetings, engaging with more than 400 international key stakeholders, also in collaboration with APs through a dedicated India-China replication meeting and a Watershare webinar.

Outcomes and insights relevant at the EU level

We deployed a balanced portfolio of sustainable circular solutions, in which climate adaptation measures and economic efficiency are not competing but are reinforcing each other. In other words, we proposed solutions that are not only adaptable to climate change and increase autonomy but are also cost-efficient.

Aligning with the EU Strategy on Adaptation to Climate Change and the European Green Deal policy framework, NextGen built on, expanded on, and shared a wealth of experiences accumulated through the development and testing of specific interventions in three key areas: water, energy, and materials. These interventions together with their modelling and assessments, provide new insights, fostering transformative change across cities and sectors of society towards climate adaptation measures and increased resilience.

For example, through Life Cycle Assessments (LCA) of all six case studies, we 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.

We have further shown that water reuse can be a good alternative to other energy-intensive options for water supply such as seawater desalination or water import over long distances and can lead to overall savings in energy demand and related GHG emissions for water supply.

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. We also highlighted some limitations to broader implementation of relevant solutions as there were techno-economic challenges to expanding their applicability and scalability; thus more studies are need to clearly highlight the advantage

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of energy recovery and reuse over conventional technologies and further research should focus on assessing economic, social and environmental benefits to support policy and regulatory frameworks and provide deeper insights into, for example, the true potential for the reuse of heat recovered from wastewater or sewage sludge at larger scales.

Regarding **nutrient recovery** from wastewater, we exposed trade-offs between chemical and energy intensive “high-tech” processes and the need for pure, high-quality products: “Low tech” nutrient recovery with sludge or compost yields more benefits in energy and GHG balance, but product quality may be lower.

Through extensive quantitative microbial risk assessment (QMRA) of water reuse we demonstrated the potential for **safe implementation of water reuse** applications for almost all tested treatment configurations. Importantly, these results are consistent with the approach proposed by the new EU Water Reuse Regulation.

A valuable lesson learned was also that, especially for water solutions, although specific costs increase with smaller plant size, this can be compensated by cost savings on energy and infrastructure for transport. It should be noted however that cost assessments simply indicate the most cost-effective solution for a given policy framework: The cost effectiveness of NextGen technologies is expected to change as these are further developed, and reach market maturity, just as environmental policy and requirements also change.

Our work also demonstrated that improved circularity could go hand in hand with reduced climate emissions and that increased autonomy is essential for **climate adaptation**; only a few of these solutions can truly be considered relevant for **climate mitigation**.

We supported the main tenet of relevant EU policies that argue that the further upscaling and transition to a circular economy requires more than ‘simply’ physical solutions: it needs the active engagement from key stakeholders and the public. We created an **engaging environment** and developed an innovative framework of systematic and holistic engagement activities:

- Communities of Practice (CoPs) meetings based on a Roadmap and Facilitation Guidelines (along with a novel social learning evaluation framework as well as reflexive learning between the different CoPs through cross-fertilisation meetings), in which bottom-up consultation was performed making it possible to co-design technologies and tools and fit innovations to local needs and settings
- Serious Games (validated through physical and online game-playing events)
- Augmented Reality (AR) applications to visualise and better understanding options, scenarios, opportunities and challenges in a more circular approach to water management,
- surveys on societal acceptability of innovative CE-based solutions, and
- a CE marketplace, in which interested parties across the water value chain can share experiences, interact and collaborate.

A further key success is the fact that the Technology Evidence Base developed in NextGen will continue to be updated with technologies after the end of NextGen through both ULTIMATE

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and B-WaterSmart projects, putting NextGen in the role of a catalyst for synergies between different initiatives.

Of direct EU added value, was the work NextGen delivered on gaps and barriers of current **policy and regulatory frameworks** that may hinder a wider uptake of circular water technologies based on the experiences of real-world cases. The project recommended potential adaptation of policy and regulatory frameworks within the scope of EU legislation (see Section 3.3).

Importantly, NextGen emphasised and embraced the term “economy”, integrating the parameter of cost and efficiency in all demo cases, an aspect more relevant than ever due to the current global energy crisis. We also explored new business models as well as created a CE Marketplace and spinoffs (see Section 3.2), bringing **new market dynamics** to circular solutions. As such, the project tangibly contributed to the further maturing of several innovative technological solutions into becoming **business opportunities** (creating new jobs and businesses) and developed instruments, methods and technologies that can help build a post-pandemic, climate and energy resilient Europe.

Last but not least, NextGen embraced **Open Science** principles, making data "as open as possible and as closed as necessary". As such most of the data produced or collected in the framework of NextGen are openly accessible with very few exceptions for reasons related to licensing issues, third party data policy, and the use of personal or sensitive data. This is an important contribution of NextGen to Open Science and Open Innovation in Europe.

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3.2 Exploitation potential

Market relevance

NextGen created new market opportunities, services, and solutions throughout the water cycle. The initial goals for exploitation were to explore new business models and support market creation to foster the circular economy development in the water sector. To this effect the project created a high-impact exploitation strategy, especially with the creation of the (i) online **marketplace** and (ii) **spinoffs** to widely commercialise project technologies.

The latter part of the strategy (spinoff creation) aimed at the creation of new sustainable economic activity, by setting up new legal entities (spinoffs) that would survive beyond the end of the project. The process started by shortlisting technologies based on relevant parameters such as maturity, TRL, added values, process, etc. Three technologies showed a particularly strong potential for the European market, and more targeted quantitative business potential assessments were undertaken for the French market. An iterative process has been applied to confirm the sustainability of the potential spinoffs and to identify which one would have the potential for start-up development. Spinoffs are perfect vehicles to deploy good practices and new technologies. It exploits the potential for impact of key NextGen technologies.

Two (out of a total of 3 that passed the go/no-go threshold) were then selected for spinoff creation: The Sewer Mining Technology and the replication of the AquaMinerals activity in France. More information on these spinoffs is provided next:

- **NEWater Source: a spinoff for water reuse in France:** This start-up is a consultancy service promoting water reuse and the sewer mining concept in France, with the NextGen unit as a possible solution. The development of the start-up shall continue within two other European projects aiming to develop an expert network and innovative technologies for water reuse.
- **Joint cooperation for upcycling water residuals – Strane/AquaMinerals:** Seitiss, a start-up developed by Strane Innovation and specialised in waste management in circular economy, has been involved in a cooperation with AquaMinerals to develop an offer for upcycling water residuals in France. Three value chains have been targeted to develop the activity: expand the use of calcite as seeding materials in EU softeners, manage and upcycle calcite pellets, manage and upcycle ferric sludge as S control agent.

EU materials and economic potential

To inspire scaling up and further promote EU added value we selected four out of 26 scenarios we analysed (see Table 3.4) and assessed the extent to which these solutions would impact EU material flows and economy if upscaled within their respective markets.

We chose technologies which have a cost similar to or lower than the cost of solutions within the current state of the art, as only such technologies can be implemented in the near future without enforced through legal obligations. The cost competitiveness of these technologies has also the positive effect that the circularity achieved is “for free”, i.e. without (much)

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additional cost. In all cases, the operational cost is of course important, but also the investment. In the case of Spernal it is particularly high since substantial new WWTP infrastructure is required (between 150 EUR/PE and 400 EUR/PE). Thus, only slow replacement can be expected, even if the technology is superior (Table 3.5).

In Table 3.6 we show the amount and value of circular products. As discussed, the technologies have a cost that can compete with the state of the art. However, the value cited here is not profit. This value is needed to cover the additional OPEX (chemicals, energy) and CAPEX of these technologies. It should be noted that they do not only produce useful materials, and energy, but also consume them. Nevertheless, some of them are overall environmentally beneficial.

Table 3.4: Selected circular scenarios for water, energy and nutrients

Demo site	Technology	Circular materials
Costa Brava	UV tertiary treatment	Irrigation water
Costa Brava	UFNF tertiary treatment aquifer recharge and retrieval	Potable water
Spernal	AnMBR and nutrient recovery with IEX	Biogas, ammonium sulphate, calcium phosphate
Altenrhein	Thermal treatment	Plant available P in ash

Table 3.5: Technology cost and market potential

Scenario	Cost relative to state of the art	Market
Costa Brava UV	Low, below desalination	Agricultural reuse[1] potential 7 billion m^3
Costa Brava UFNF	Medium, below desalination	Coastal application (<15 km), water stress (ES, PT, ES, EL), WWTP with N elimination[2]: 5 billion m^3
Spernal AnMBR/IEX	OPEX below activated sludge (AS) process with nutrient elimination. CAPEX similar to AS.	All WWTP over 100000 PE (55 Mio PE). 1% of total capacity over 10 years (5.5 Mio PE).
Altenrhein PK fertilizer	Lower than mono-incineration	Sludge in agriculture not allowed or phosphorus recovery obligatory (DE, AT, NL) 150 Mio PE, 20% market share

Table 3.6: Amount and value of circular outputs

Scenario	Amount of circular material	Value (Million EUR)[3]
Costa Brava UV	7 billion m^3 of irrigation water with nutrients	3500
Costa Brava UFNF	5 billion m^3 of potable water in water stressed coastal area	2500
Spernal	280 Mio Nm^3 CH_4/a (3 TWh/a)	280
AnMBR/IEX	0.18 Mio t N/a	190
	0.03 Mio t P/a	50
Altenrhein PK fertilizer	0.02 Mio t P/a	28

[1] Potential at low cost for implementation, short distance etc.: EC (2018) Commission Staff Working Document Impact Assessment for Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse

[2] 50% as reported in Office International de l'Eau, Umweltbundesamt, Ramboll (2022) 11th Technical Assessment on UWWTD implementation doi:10.2779/915400

[3] Cost data from 2021 or earlier. Irrigation and potable water 0.5 EUR/m^3. Natural gas 100 EUR/MWh, 1040 EUR/t N. 1500 EUR/t P

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Contribution to Research and Innovation

a) Contribution to Research

Technology Evidence Base

Several technologies related to circular economy in the water sector were investigated at the 10 NextGen case studies across Europe. These technologies include solutions for water management and recovery, materials recovery, and energy recovery. In this context, a database containing information and data referring to those technologies was developed. The database is called Technology Evidence Base (TEB), is open access and hosted by Water Europe as part of the Marketplace. It's important to note that several of the demonstrated CE technologies **provide multiple services**, in that they can contribute to the recovery of more than one product. E.g., the anaerobic membrane bioreactor (AnMBR), is an important part of the treatment train to recover fit-for-purpose water, but also recovers energy in the form of biogas production. The structure of the TEB was developed specifically to allow such solutions to be identified as solutions to multiple challenges. This flexible and combined scheme favours and further promotes technologies, tools and applications that combine more than one domain within a unified CE concept. In summary, the TEB is flexible and expandable and able to accommodate the particularities and attributes of a wide range of technologies, tools, products, or demo cases. This generic approach adopted for the creation of the TEB has a significant exploitation potential as it can be updated and enhanced with new technologies, tools or applications around the CE-based water sector well beyond the project. This is already creating synergies between relevant projects (see Section 3.1)

Papers on circular technologies

A series of papers have been published during the project (> 40) including work both on technological innovations (e.g., rainwater harvesting, sewer mining) and social innovations (e.g., CoPs for social learning, AR for user engagement, work on public acceptance, etc.) and their combinations further strengthening the European evidence base and scientific leadership in the field of CE. See list in Section 2.6.

b) Contribution to Innovation

To commercialise our innovative technologies, we created spinoffs (see above), an online marketplace, and collaborated with our SME partners.

CE Marketplace

The CE Marketplace (mp.watereurope.eu), which begun its product life as NextGen MP, was created to serve as a meeting place for stakeholders of the circular economy, allowing them to seek solutions or promote innovative scientific and technical solutions in the fields of water, energy, and materials. The project specifically customised the Marketplace's capabilities to the requirements of Water Europe to ensure its long-term viability.

Over the last two years, the platform, has gained over 2100 new members. So far, 132 of them have registered to take full advantage of the platform's capabilities. The hosting of platform by Water Europe is a key element of exploitation and ensures that the platform will be continuously updated with new material, new events, f2f meetings, and sharing of knowledge,

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best practices and experiences from circular water solutions and innovative demo cases well beyond the end of the project.

Exploitation by and impact to existing SMEs

NextGen's impact on the SMEs that were partners in the project is briefly presented next:

Strane is a start-up studio dedicated to waste management, water management and circular economy. NextGen allowed Strane to gain expertise in water management, and the tools developed within NextGen (circular business models, circular value chains) support these activities. Strane aims to replicate the NextGen methodology and good practices in other European projects for high impact exploitation activities. NextGen has led to two new businesses for Strane: a joint cooperation for water upcycling in France with AquaMinerals about calcite and ferric sludge value chains; the start-up project NEWater Source consultancy service to promote water reuse in France.

AquaMinerals (AqM) markets recovered products from the waters sector. NextGen has led to direct new business for AquaMinerals: calcite value chains in France (cooperation with Strane); iron Sludge value chains in France (cooperation with Strane); struvite values chain in Germany (lead from Braunsweich-partners). AqM has obtained very valuable information on success and failure factors setting up new circular value chains. This helps AqM and other companies that use this info on shortening the time to market, decreasing the failure rate and reducing innovations costs. AqM is based in the Netherlands and had >80% of its turnover there. This project has widened its view and created new networks. Appointments have been made for after the NextGen project to further investigate cooperation and/or exporting technology.

Biopolus was created upon the concept of water-based urban circularity, where multi-level circular processes and technologies are integrated to create a tangible circular business model for a bioeconomy. Using the experiences and partnerships gained through NextGen, Biopolus will continue to further develop its business model and circular technologies for water treatment, organic recovery, and urban plant factories. NextGen proved that decentralized circular technologies are needed to create locally available sustainable solutions. However, further development is needed to turn these solutions into successful new circular business models, which can be replicated globally. Biopolus will continue to push for a shift toward financially viable, sustainable, decentralized circular urban solutions.

SEMiLLA IPStar is the technology transfer entity of the European Space Agency's (ESA) consortium in charge of developing circular systems (MELISSA). ESA is keen to transfer knowledge between our circular technologies (such as the Metabolic Network Reactor) and those developed for the extreme circular constraints present in the context of space exploration and identify synergies. ESA has expressed interest to continue collaboration in their test locations for future EU CE projects.

BDG, Business Development Group, will use NextGen results to support CE implementation in the Romanian water sector, raise local awareness, and identify business models to support resource recovery.

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3.3 Policy relevance

Supportive regulations are essential for an efficient circular transition. In a European context, where water can be considered as a transnational good, a harmonized regulation is essential for the development of a European circular market. The EU Circular Economy Action Plan aims to streamline regulations made fit for a sustainable future. With relevance to the water sector, the EU CE Action Plan will facilitate water reuse and efficiency, and a new Water Reuse Regulation is put into place. Our regulatory assessments revealed concerns on the compliance and harmonisation of the Water Reuse Regulation within each Member State's (MS) national structures. Moreover, the wide variation among MS and an overall regulatory gap around addressing smaller-scale circular solutions creates uncertainty (planning and building regulatory frameworks). For energy and materials recovery, the growing interest around these technologies amongst utilities in the European sector has not yet been matched with the emergence of a coherent policy and regulatory framework around technology adoption and bringing products to market.

EU Policy recommendations

Based on the experiences of the NextGen demo cases, we recommended potential 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. Further, we recommended the creation of simpler, and less costly routes to market for recovered resources. The revised Fertilising Products Regulation, the announced review of the Sewage Sludge Directive, and the development of an Integrated Nutrient Management Plan can ensure more sustainable application of nutrients and stimulate the markets for recovered nutrients. We also argue that seizing the opportunity for circular solutions to become part of the ESG (Environmental, Social and Governance) investment landscape would create significant new opportunities.

Several of the recommendations have been taken up in the revised Urban Wastewater Treatment Directive, released for consultation in October 2022. In particular, the revised directive seeks to drive the water and wastewater sector towards energy neutrality, and provide greater incentive particularly for water reuse and the recovery of biogas and phosphorus. It also proposes to expand the scope of the directive to cover rainwater and the establishment of integrated urban wastewater management plans, which should create opportunities for decentralised, small-scale circular systems such as rainwater harvesting.

Ultimately, to support the EU wide uptake of circular water solutions, 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.

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4. Conclusion

4.1 Key messages

NextGen has challenged embedded thinking and practices in the water sector by embracing circular economy principles and technological innovation. Specifically:

1. NextGen **unlocked the potential** of the circular economy in the water sector, by demonstrating recovery and reuse of water-embedded resources in ten demo cases spread across different European regions in eight countries.
2. NextGen **demonstrated the benefits** of circular water solutions in reducing water, energy and materials consumption, in preventing 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
3. 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.
4. 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.
5. 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.

4.2 Takeaway summary

The NextGen EU-H2020 project has been working towards revolutionizing the water industry through the application of circular economy principles and by developing the technological innovations needed to apply those principles in practice. To demonstrate the potential of these approaches, NextGen conducted 10 demonstration cases in various locations across Europe, showcasing the benefits of circular water solutions, such as reduced consumption of water, energy, and materials, prevention of pollution, and the added value of recovered resources that can be utilized in other sectors.

Specifically, NextGen demonstrated 26 different circular water technologies, providing evidence that it is technically possible to transform wastewater, sourced from treatment plants or even directly mined from sewers, into high-quality, commercially valuable products such as reclaimed water, energy (in the form of biogas and heat), and reusable materials like nitrogen and phosphorous. These products can act as "alternative sources" for meeting a range of non-potable water demands, energy needs, and the production of fertilizers and

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other commercial goods. This benefits the quality of life, especially in dense urban environments, shielding the economy from climatic and market stresses.

In addition to this, NextGen argued that transitioning from a linear to a circular economy requires a shift from a traditional cost-benefit approach to business models based on circular value chains and conducted assessments of both established and circular value chains in the demonstration cases. For selected circular solutions, market assessments and business plans were also developed. To further exploit the potential of these solutions in the real world, NextGen launched three spin-off companies.

Importantly, the project invested heavily in EU wide replication, open knowledge exchange and in catalysing novel circular economy business opportunities by creating an online marketplace for Water in the Circular Economy. This marketplace is hosted by Water Europe, guaranteeing its long-term viability, which showcases circular water technologies, tools for assessing the environmental and economic impact of these technologies, and best practices for implementing circular economy solutions.

NextGen informed policy, by highlighting the need for better aligned EU directives that incentivise circularity, better support for the implementation of the Water Reuse Regulation and arguing for the urgent need to simplify, and reduce the cost of, alternative routes to market for recovered resources. Finally, to support wide uptake of circular water solutions across the EU, NextGen proposed a comprehensive ‘package’ of technological, economic, socio-cultural and regulatory measures.

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Annex A: List of Partners

No	Name	Short name	Country
1	KWR WATER B.V.	KWR	Netherlands
2	KWB KOMPENTENTZZENTRUM WASSER BERLIN GEMEINNUTZIGE GMBH	KWB	Germany
3	FACHHOCHSCHULE NORDWESTSCHWEIZ	FHNW	Switzerland
4	CRANFIELD UNIVERSITY	UCRAN	United Kingdom
5	STRANE INNOVATION	STRANE	France
6	FUNDACIO EURECAT	EUT	Spain
7	IVL SVENSKA MILJOEINSTITUTET AB	IVL	Sweden
8	NATIONAL TECHNICAL UNIVERSITY OF ATHENS - NTUA	NTUA	Greece
9	THE UNIVERSITY OF EXETER	UNEXE	United Kingdom
10	INSTITUTE OF COMMUNICATION AND COMPUTER SYSTEMS	ICCS	Greece
11	EUROPEAN SCIENCE COMMUNICATION INSTITUTE (ESCI) GGMBH	ESCI	Germany
12	UNIVERSITY OF BATH	UBATH	United Kingdom
13	IPSTAR BV	IPSTAR	Netherlands
14	BIOPOLUS INTEZET NONPROFIT ZRT.	BIOPOL	Hungary
15	WATER EUROPE	WE	Belgium
17	ABWASSERVERBAND BRAUNSCHWEIG	AVB	Germany
18	YTL PROPERTY HOLDINGS (UK) LIMITED	YTL	United Kingdom
19	SEVERN TRENT WATER LIMITED	STW	United Kingdom
20	AQUAMINERALS BV	AQM	Netherlands
21	Provincie Zuid-Holland	PZH	Netherlands
22	WATERSCHAP DE DOMMEL	WdD	Netherlands

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23	ADASA SISTEMAS, S.A.U.	ADASA	Spain
24	Agència Catalana de l'Aigua	ACA	Spain
25	ETAIREIA YDREYSEOS KAI APOCHETEFSEOS PROTEYOYSIS ANONIMI ETAIREIA	EYDAP	Greece
26	DIMOS ATHINAION	CoA	Greece
27	CHEMITAL TECHNOLOGY P. DIMOPOULOU -P. TAZES & CO OE	CHEM	Greece
28	GOTLANDS KOMMUN	RoG	Sweden
29	ABWASSERVERBAND ALTENRHEIN	AVA	Switzerland
30	CTU CLEAN TECHNOLOGY UNIVERSE AG	CTU	Switzerland
31*	AQUATIM SA	AQT	Romania
32*	BUSINESS DEVELOPMENT GROUP SRL	BDG	Romania
	International and associated partners: • Korea Institute of Science and Technology • Jiangsu Zhongyi Huanke Environmental Science and Technology Development Co., LTD • Taposya Social Welfare Organisation	KIST JIANGSU TSWO	South Korea China India

** New partners from 01/01/2020 (replacing partner no. 16 ANB)*

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Annex B: List of Deliverables

#	Deliverables	Public report (yes/no)
D1.1	Assessment of baseline conditions for all demo cases	Yes
D1.2	Operational demo cases	Yes
D1.3	New approaches and best practices for closing the water cycle	Yes
D1.4	New approaches and best practices for closing the energy cycle in the water sector	Yes
D1.5	New approaches and best practices for closing materials cycle in the water sector	Yes
D1.6	Technology Evidence Base initial version	Yes
D1.7	Technology Evidence Base final version	Yes
D1.8	Greenfield implementation in Filton Airfield	Yes
D2.1	Environmental Life Cycle Assessment and risk analysis of NextGen demo cases solutions	Yes
D2.2	Economic assessment and cost efficiency analysis of NextGen demo cases solutions	Yes
D2.3	Re-design and stress test of NextGen selected case study systems	Yes
D2.4	NextGen Water in the CE re-design toolbox initial version	Yes
D2.5	NextGen Water in the CE re-design toolbox final version	Yes
D3.1	Community of Practice Roadmap and Facilitation Guidelines	Yes
D3.2	Augmented Reality Application, deployed in 3 demo cases initial version	No
D3.3	Serious Game for Water in the CE, initial version	Yes
D3.4	Public engagement through Living Labs	Yes
D3.5	CoP's cross-fertilisation report	Yes
D3.6	Augmented Reality Application, deployed in 3 CS demo cases, final version	No
D3.7	Serious Game for Water in the CE final version	Yes

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D4.1	Interim report, with preliminary findings, on societal acceptability	No
D4.2	Final report on societal acceptability – Part A & Part B	Yes
D4.3	Final report on challenges and opportunities across policy and regulatory frameworks	Yes
D4.4	Roadmap to addressing governance and societal challenges to support wider uptake of circular solutions in the water sector	Yes
D5.1	New business models and services related to CE	Yes
D5.2	Assessment of NextGen value chains	Yes
D5.3	Market and competition assessment	No
D5.4	Business plan	No
D5.5	The NextGen Online Marketplace	No
D6.1	Communication & Collaboration Master Plan	Yes
D6.2	Interim report on editorial, video and visual content and distribution	No
D6.3	Report on editorial, video and visual content and distribution	Yes
D6.4	Report on replication potential and outreach in international markets	Yes
D6.5	Report on impact of external events and academic papers	Yes
D7.1	Scientific quality assurance plan	Yes
D7.2	Data Management Plan initial version	Yes
D7.3	Data Management Plan updated version	Yes
D7.4	Data Management Plan final version	Yes
D7.5	Synergies report	Yes
D7.6	NextGen final report	Yes
D8.1	H - Requirement No. 3	No
D8.2	POPD - Requirement No. 4	No

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Annex C: Main results from the technology demonstrations at the NextGen demo cases

In this Annex, the main results of the WP1 technology demonstrations at the ten NextGen demo cases are presented. For each demo case, the relevant water, energy and materials outcomes are described combined. The detailed results are published in the Deliverables related to either closing the water, the energy or materials cycles (D1.3, D1.4 and D1.5) and for a greenfield implementation (Filton Airfield D1.8).

Braunschweig

Steinhof, near Braunschweig, has a long tradition of water and nutrient reuse. Already at the end of the 19th century, fields were irrigated with sewage. From 1954 on, the wastewater was mechanically clarified and reused for irrigation. Finally, in 1979, the wastewater treatment plant (WWTP) was built and comprised a conventional activated sludge treatment system and a digestion stage. Until 2016, in summer, the digestate was directly reused in agriculture, while in winter, the digestate was dewatered and stored until the summer season. However, due to the new legislation in Germany, since 2017 only 60% of the digestate can be applied on the fields. The reasons are restricted periods for fertilizing with digested sewage sludge and the limitation of the nitrogen load to the agricultural fields. Thus, the other 40% of the digestate were dewatered and incinerated. In 2019, a new circular economy concept was implemented. Here, energy recovery technologies are combined with nutrient recovery technologies. Therefore, sludge management concept was adapted to increase the nutrient recovery rate and simultaneously, as a synergetic effect, the biogas recovery rate increased. Hence, circular economy solution comprises a thermal hydrolysis process between two digestion stages and a full-scale nutrient recovery plant consisting of a struvite production unit to recover phosphorus and an ammonium sulphate solution production unit to recover nitrogen. The secondary fertilizers will be reused by the local farmers and the produced energy in the form of biogas and heat is reused by the plant itself.

Applied solutions

Enhancing biogas production via thermal pressure hydrolysis

The goal of the Braunschweig (DE) case was to enhance biogas production via thermal pressure hydrolysis at the municipal WWTP. Thermal pressure hydrolysis (TRL 9) was performed as a pre-treatment of digestion, resulting in higher biodegradation during digestion. The results showed that the biogas production increased by 20% and the dewatering efficiency of the digestate increased by 10% due to the higher biodegradation of the thermally hydrolysed sludge. Although high attention to operating and maintenance of the system is mandatory, the technical feasibility of the thermal pressure hydrolysis has been successfully demonstrated. The better biodegradation contributed also to an increase in

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phosphate and ammonium concentrations in the liquor, which are crucial for the subsequent nutrient recovery.

Nutrient recovery (struvite, ammonium sulphate)

Nutrient recovery at TRL 9 was successfully demonstrated. To remove and recovery phosphorus, the struvite production unit used the liquor of dewatered digestate in a side stream and reached recovery rates between 80%-97%. The recovery rate depended highly on the chemical composition of the liquor, the mixing conditions in the precipitation reactor and the dosing rates of MgCl2. The potential for struvite production is 300 t struvite/a. For nitrogen removal and recovery, an air stripping and scrubbing unit was implemented to produce ammonium sulphate solution. The recovery rates were easy to control and could be operated between 80% and 97% as required. The potential to produce (NH4)2SO4 solution is 2000 t/a.

Summary of solutions and main outcomes for Braunschweig

Subtask	NextGen solution	TRL	Capacity	Product	Quantifiable target
Sub-task 1.3.2	Thermal pressure hydrolysis and two-stage digestion	TRL 8 → 9	Feed with dry matter 10-13% of wet weight;	Energy to be reused Reuse within the WWTP: Digestion, CHP and buildings	Increase in biogas production: 20%
Sub-task 1.4.7	Ammonia stripping & scrubbing to produce ammonium sulphate solution	TRL 9	7-19 m^3 liquor/h; 380 000 PE: 175 t N/a	Ammonia sulphite	Ammonium sulphate solution production: 85-97% recovery from N load to recovery unit
	Phosphorus recovery for struvite production	TRL 9	7-19 m^3 liquor/h; 380 000 PE: 175 t N/a	Struvite	≥80% recovery from P load to recovery unit

Costa Brava Region

Costa Brava is a region with high seasonal water demand and frequent water scarcity episodes, which can also cause saltwater intrusion. It is one of the first areas applying water reuse in Europe. In total, 14 full-scale tertiary treatments provide 4 Mm^3/year (2016) for agricultural irrigation, environmental uses, non-potable urban uses and, recently, indirect potable reuse. The Tossa de Mar WWTP works with one-line tertiary treatment with an average flow rate of 7.4 m^3/h, ranging from 4.5 m3/h during the winter period (values from 2018) to a maximum of 11 m^3/h reached in summer. Mainly during the summer period, both the number of tourists and the wastewater flow rate to be treated increases: thus, a part of the effluent from the secondary treatment is sequentially treated by its tertiary treatment (flocculation/coagulation, pre-chlorination, sand filtration and disinfection process with UV lamps and chlorination). Currently, the effluent from tertiary system is used for agricultural irrigation and environmental and non-potable water uses. The excess water flows to the sea. Due to the increase on water demand, especially during summer period, it is needed to improve the final quality of regenerated water for broadening its application in more restrictive reuses such as private garden irrigation or indirect potable reuse. This goal is pursued by the NextGen pilot plant. In the case study, a pilot plant integrated by ultrafiltration

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(UF) and nanofiltration (NF) modules fitted with RO regenerated membranes was installed in December 2019 at the WWTP of Tossa de Mar. The pilot plant was allocated after the sand filter of the tertiary treatment of the WWTP. It will operate for 1 year in (2020-2021). During this period, the operation conditions of this new system are evaluated, as well as the quality of the water obtained to be used for the irrigation of private gardens.

Applied solutions

Ultrafiltration and nanofiltration with RO regenerated membranes

The main objective of the Costa Brava (ES) case study was to demonstrate the performance of regenerated end-of-life RO membranes with a porosity of NF. The water quality obtained meet the quality required for private irrigation according to RD1620/2007 (Spanish legislation for water reuse) being able to produce 2 m3/h and to remove > 75% of the salinity, about 80% of trace organic compounds (such as pesticides, pharmaceuticals, endocrine disruptors), and > 95% of turbidity and TSS. Remarkably, the energy consumption of NF membranes was lower than the consumption of commercial NF membranes, i.e. 0.9 – 1 kWh/m3 compared to 2 kWh/m3.

Summary of solutions and main outcomes for Costa Brava

Subtasks	NextGen solution	TRL	Capacity	Product	Quantifiable target
Sub-Task 1.2.2	UF and NF modules are fitted with regenerated RO membranes used as a final treatment of urban effluents in the WWTP of Tossa de Mar	TRL 5 → 7	Pilot plant which produces 2 m^3/h of reclaimed water	Reclaimed water for private uses and Indirect potable reuses according to Spanish regulation RD 1620/2007	2 m^3/h of reclaimed water Theoretically: Indirect Potable Reuse by aquifers recharge

Westland Region

The Westland region in the Netherlands are dense urban and industrial areas and greenhouse horticulture complexes. The main objective of the Westland demo case is the demonstration of an integrated approach for a circular water system. In the region already numerous initiatives exist of circular technologies related to e.g. rainwater harvesting and reuse in horticulture, aquifer thermal energy storage, and resource recovery from WWTPs. In NextGen, a regional management strategy for a circular water-energy-materials system is implemented, supported by a CoP to have active cooperation between stakeholders.

For their water demand, the horticulture companies use rainwater harvesting basins, complemented with groundwater desalination technologies. Scenarios for alternatives that further close the water system are developed, that include Aquifer Storage & Recovery and WWTP effluent reuse as water sources for the horticulture.

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For their heat demand, several clusters of greenhouses already have, or are developing, a geothermal well. However, none of these clusters have a large scale heat buffer to overcome the temporal mismatch. High Temperature Aquifer Thermal Energy Storage (HT-ATES) systems are a cost-effective method for large scale heat storage in areas where aquifers are available, like in the Westland. At the horticulture company Koppert Cress, an ATES system is being converted to an HT-ATES system.

Applied solutions

Aquifer storage and recovery systems

Conventional aquifer storage and recovery (ASR) renders relatively low recovery efficiencies in the Westland area (about 30%, whereas the recovery can increase to >90% for a fresh groundwater environment) because of mixing of the injected rainwater with the brackish groundwater. From an environmental perspective it is still useful to infiltrate excess rainwater through water banking (balancing extraction with infiltration), as it counteracts salinization and reduces flood risk. Implementing water banking at about half of the horticulture companies in Westland can result in an almost zero net groundwater extraction (defined as the total amount of groundwater extraction minus rainwater infiltration). The unsustainable groundwater abstraction would be reduced from 3.75 to 0.7 Mm^3/y (>80%). About 5% of the effluent from two nearby WWTPs would provide sufficient irrigation water for the horticulture greenhouses as an alternative water source.

Aquifer thermal energy storage

A high-temperature aquifer thermal energy storage (HT-ATES) system was explored in the Westland region (NL) to store residual heat that can be used for the heat demand of horticulture companies. The results showed that there is sufficient residual heat available and that the aquifers are suitable for the application of ATES systems to store the heat. Residual heat in the Province of South Holland could contribute 100% of the heat demand of the horticulture companies in Westland. ATES systems can secure 10-15 PJ seasonal storage, which is sufficient for 10-15% of the annual total energy demand. The currently expected number of geothermal wells combined with HT-ATES can meet about 5% of the heating demand of the horticulture cluster Polanen. The performance of the HT-ATES system at Koppert Cress in the current situation shows that, although the heat recovery factor for the warm well is good (0.7-0.95, the expected value was 0.89 as shown in Table 1), the heat demand is not reached. The expected future addition of a geothermal heat source can provide in the required amount of extra heat. Large scale adoption of HT-ATES in the Westland could potentially save about 250 Mm^3 natural gas per year, which reduces the greenhouse gas (GHG) emissions with about 500 kt per year. The case study concluded that at the individual project/site level HT-ATES is technically, legally and financially feasible. The experiences of applying ATES at high temperatures illustrated the potential of HT-ATES by show-casing the increase in energy performance and CO_2 emission reductions of the greenhouse of the horticulture company Koppert Cress.

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Summary of solutions and main outcomes for Westland

Subtasks	NextGen solution	TRL	Capacity	Product	Quantifiable target
Sub-task 1.2.1	Aquifer Storage systems: ASR / water banking	For ASR: TRL 7/8 → 9 For water banking: TRL 7	8500 m^3/ha/year of rainwater stored	Horticulture irrigation according to groundwater quality related regulations	Theoretical study; aquifer rainwater storage: 4.8 Mm^3/y; 80 % reduction of net groundwater extraction
Sub-task 1.3.5	High Temperature-Aquifer Thermal Energy Storage system (HT-ATES)	TRL 4 → 6	4200 MWh/y charged, and 3750 MWh/y discharged	Heating demand for horticulture	Reached value: Temp: 20-45°C, Cooling demand 11 TJ / Heating demand 20 TJ Heat recovery factor: 0.7-0.95 (warm well) & 0.3-0.5 (cold well)

Altenrhein

The WWTP of Altenrhein operates residential drainage-, wastewater- and sludge treatment of 17 municipalities in two federal states (St. Gallen and Appenzell-Ausserrhoden).
The treated water reaches Lake of Constance via the mouth of the Old Rhine. Both Lake of Constance and the Old Rhine are considered priority water bodies for protection. Lake of Constance also serves as a drinking water reservoir. The topographical conditions around these 17 municipalities vary greatly which makes the water transportation more challenging. For this reason, special structures are required. Sludge that is being treated in Altenrhein originates from their own water treatment and is also being transported to the site by other WWTP of Eastern Switzerland. The WWTP of Altenrhein (AVA) has advanced energy-efficient sludge management technologies for 300.000 pe of sludge: sludge is dried on site and is co-incinerated in cement works. The heat for sludge drying is generated by burning of sewage gas and by heat recovery from wastewater using heat pumps. AVA took a full-scale removal of micropollutants by ozonation and active carbon adsorption into operation in 2019 and a ammonia membrane stripping unit from sludge dewatering employing an innovative membrane contactor with a novel low fouling membrane module in 2021 a total investment of EUR 20 Mio in innovative technologies. After the project AVA will have a clear idea of the technical and financial feasibility of on-site activated carbon regeneration and production of fresh activated carbon using locally available sludge and biomass. Long-term experience with full-scale installations for micropollutant removal and N recovery gained with the installations at Altenrhein will reduce investment risks, enhance chances of replicability. AVA also gathers all necessary information to take an investment decision regarding the construction of a P-K fertilizer production unit. This novel thermochemical process transforms sewage sludge into a market grade P-K-fertilizer. Thereby heavy metals are partly removed and the fully plant available mineral phase CaKPO4 is produced. The process has been piloted in a large-scale pilot to gain further operational experience.

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Applied solutions

Ammonium sulphate production

In Altenrhein, also a hollow fibre membrane contactor (HFMC) was tested, however in a side stream for the concentrate of dewatered digestate at TRL 8. The recovery rate was 75% in the pilot plant. Hence, the recovery of a full-scale system (305 000 PE) of 66 t N/a can be expected for Altenrhein. This corresponds to 11% of the nitrogen inflow load to the WWTP.

Granular activated carbon production via pyrolysis

In Altenrhein, a pyrolysis process was tested as a side stream treatment of dried digestate to produce granular activated carbon (GAC). The renewable sewage sludge GAC has only a fraction of the active surface of the conventional GAC and also the pore volume is smaller. It has a good hardness suggesting good resistance to typical stresses in fixed bed contactors. The recovery rate was 50% GAC and 50% pyrolysis gas. The GAC produced from sludge was suitable for a pre-treatment to remove micropollutants upstream of a conventional GAC filter to prolong its lifetime.

PK-fertiliser production via thermal treatment

In Altenrhein, a thermal treatment was tested using dried digestate as side stream technology. Its TRL reached 8 and the recovery rate ranged between 90% and 100%. Since this treatment does only partly remove heavy metals, a detailed characterisation of the feed stream is necessary and an application using "clean" digestate or waste streams from the food industry might be even more beneficial. Using digestate from a municipal WWTP as feed stream, 0.95 kg P/h was achieved in the pilot plant. This corresponds to the recovery of 390 t P/a for a 305 000 PE full-scale plant. Those correspond to 12% of the influent phosphorus load of the WWTP.

Summary of solutions and main outcomes for Altenrhein

Subtasks	NextGen solutions	TRL	Capacity		Quantifiable target
Sub-task 1.4.3	Production of renewable GAC via pyrolysis, activation	TRL 5 → 6	Production: 1 kg/h Filtration: 0.2 m^3/h	Granular activated carbon	50% GAC, 50% gas, sieving losses
Sub-task 1.4.1	Implementation of a hollow fibre membrane contactor for ammonia recovery as $(NH_4)_2SO_4$	TRL 7 → 8	Input: 8 ^{3}/h	Ammonium sulphate	Recovery rate: 75%
Sub-task 1.4.2	P recovery via pyrolysis as PK-fertiliser	TRL 5 → 7	Input: 20-50 kg/h	PK-fertilised	Recovery rate: 90-97%

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Spernal

Spernal WWTP serves the towns of Redditch and Studley located approximately 24 km south of Birmingham (UK). The area has a residential population of approximately 85,000. The treated effluent is currently discharged to the River Arrow, which is designated as a sensitive area under the Urban Wastewater Treatment Directive (UWWTD) and has an overall water body status of moderate under the Water Framework Directive (WFD). Sludge from the site and other local rural works is treated in conventional anaerobic digesters and dewatered before being recycled to local farmland and industries. The biogas produced by digesters is burnt in combined heat and power (CHP) engines to produce heat and electricity. A multi-stream technology demonstration plant incorporates an anaerobic membrane bioreactor (AnMBR) complete with a membrane degassing unit to recover dissolved methane for water and energy reuse, and a pilot scale nutrient adsorption step for nitrogen and phosphorus recovery. Through such demonstration to close the water, energy and materials cycles, the necessary data to assess the benefits of the technologies will be provided.

Applied solutions

Anaerobic membrane bioreactor

Solids management in the anaerobic membrane bioreactor (AnMBR) is of vital importance, as these must be retained in the UASB reactor for as long as possible to go through hydrolysis followed by the 3 other stages of anaerobic digestion and ultimately result in biogas production. Further, the solids should not find their way to the UF to avoid fouling issues.
The AnMBR operational efficiency achieved in this study was comparable to previous studies with variable influent municipal wastewater values for COD of 221-455 mg/L and TSS of 45-479 mg/L. The removal rates achieved for the COD and BOD5 were still lower compared to other studies that obtained 83 ± 7% and 90 ± 6%, respectively, but similar values are expected once the AnMBR reaches stable operation. A granular sludge inoculated AnMBR also can achieve an sCOD removal of 43 ± 15%, also similar to this study's results. The removal efficiency of a self-forming hollow fibre dynamic membrane was only around 42% and 34% for TSS and VSS. The similar reactors design of this study to previous studies emphasise the validity of the results and work performed. The operational temperature range was also similar to previous studies: operated at 18 ± 2ºC and 16.3 ± 3.7ºC. Regardless of the high COD influent in the systems, the methane yield reported was considered average. This was mainly because no solids could escape the system and hydrolysis was maximised during operation, which in turn ensured methane yields were high.

Decentralized energy recovery from anaerobic membrane bioreactor

Decentralized energy recovery from an anaerobic membrane reactor combined with a methane degassing system was tested at the Spernal wastewater treatment plant. The membrane degassing system demonstrated in Spernal can potentially recover methane from the AnMBR effluent to a dissolved methane concentration of 0.14 mg/L from an initial concentration of 20 mg/L (99% removal, designed values). The membranes are designed to operate at 2 Nm3/h gas at 60 mbar. In addition, liquid ring vacuum pump technology was chosen to generate the vacuum. This system has several benefits, including the potential for energy neutrality, compact size with a low carbon footprint and low operation costs. The energy production on the Spernal demonstrator originates from the biogas produced in the

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AnMBR. On average the biogas yield recorded was 0.15 m3 CH4/kg COD removed, this includes the dissolved methane part of the biogas production. Two scenarios were considered: (a) generation of electricity and heat via CHP and (b) upgrading of biogas for grid injection. Based on the scenarios, the theoretically recoverable energy was estimated for a capacity of 200 m3/day (i.e., AnMBR effluent as a feed). Thus, it was expected to produce 44 kWh/day electricity and ~ 50kWh heat/d (assuming around 15% losses) for scenario (a) and 108 kWh/d of biogas for scenario (b). However, during the NextGen project, the methane degassing system has not been capable of recovering dissolved methane from AnMBR effluent that can be used as an energy source. This was mainly due to the influent wastewater quality, in particular sulphate. At present, the methane degassing system is given more attention by engineers/operators to reach higher TRL.

Nutrient recovery (ammonium sulphate and hydroxyapatite)

In Spernal, ammonium sulphate and hydroxyapatite were produced as a mainstream treatment using the effluent of an anaerobic membrane bioreactor combined with an ion exchanger. For ammonia sulphate production, the TRL reached TRL 6 suggesting, that further investigations are necessary prior to its replication at full-scale. The system was applied in the effluent of an anaerobic membrane bioreactor as a mainstream technology. It consisted of an ion exchanger to concentrate the ammonium and a hollow fibre membrane contactor (HFMC) for ammonia stripping and ammonium sulphate production. The recovery rates for the ion exchanger and the HFMC were >80% and > 95%, respectively, resulting in a nitrogen recovery rate higher than 76%. Based on those results, the production of ammonium sulphate in a full-scale system for 100 000 PE is assumed to result in the recovery of 320 t N/a. This corresponds to 88% of the inflow nitrogen load to the WWTP.

The ion exchanger was also used to concentrate the phosphate concentration in order to precipitate the phosphate as hydroxyapatite in the subsequent precipitator. A TRL of 7 was reached suggesting to further optimise the system. The recovery rates for the ion exchanger and the precipitator were >80% and > 90%, respectively. Based on those results, a full-scale system (100 000 PE) can recover 61 t P/a, what corresponds to 80% of the P load in the influent of the WWTP.

Summary of solutions and main outcomes for Spernal

Subtasks	NextGen solutions	TRL	Capacity	Product	Quantifiable target
Sub-Task 1.2.3	Decentralized water treatment by a multi-stream anaerobic membrane bioreactor (AnMBR)	TRL 6 → 7	500 m3/d (max)	Reclaimed water for farming and industrial uses. No water reuse guidelines in the UK	Pathogen and solids free effluent which can be reused in several applications.
Sub-Task 1.3.3	Decentralized energy recovery and usage from anaerobic MBR	TRL 7→ 8	200 m^3/day	Energy produced to be reused within the WWTP or export of electricity or	200 m3/day; Electricity & heat produced for the two scenarios: 1.CHP-electricity and heat: 44 kWh/day and ~ 50kWh

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				biomethane to grid.	heat/d (assuming around 15% losses) 2. Biogas upgrading: 108 kWh/d
Sub-task 1.4.5	Ion exchange and hollow fibre membrane contactor	TRL 6 →7	1 m^3 AnMBR effluent/d	Ammonium sulphate or ammonia solution	Recovery rates: N: > 76%; IEX: >80%; HFMC: >95%
	Ion exchange and precipitation	TRL 6 → 7		Hydroxyapatite	Recovery: P: > 72%; IEX >80%; precipitator >90%

La Trappe

At the La Trappe brewery Koningshoeven, a BioMakery biological wastewater treatment system was installed. The BioMakery is powered by Metabolic Network Reactor (MNR) technology, which uses 2-3,000 different species of organisms ranging from bacteria to higher level organisms such as plants. The BioMakery serves as a test facility for advanced circular space technology developed within the micro-ecological life support system alternative (MELiSSA) program of the European Space Agency (ESA). SEMiLLA formerly known as IPStar has a mandate to implement this technology in civil society. Coupling MNR with MELiSSA advanced separation and photobioreaction based technologies, reusable process and/or irrigation water will be produced, while also growing biomass that can be used as slow-release fertilizer for the plant nursery, as fish fodder, or as human food.

Applied solutions

Metabolic Network Reactor coupled to a Micro-Ecologial Life Support System Alternative (MELiSSA) advanced separation systems (MF/RO)

Before the installation of the Metabolic Network Reactor (MNR) and MELiSSA systems the effluent from the brewery was released into the public sewerage network of Tilburg. The treatment took place in the Tilburg municipal wastewater treatment plant, located approximately 9km from the brewery, at the opposite end of the city. The transport of high strength wastewater over long distances can cause issues in the sewer lines, such as deposition of solids and anaerobic decomposition resulting in emission of odors and corrosive gases. The performance expected of the MNR unit was with a 99% of water yield, a 97.6%, 99.7% and 99% of BOD, COD and turbidity were removed. Assuming stable operation of the MNR, high quality effluent could be produced. However, due to lower than expected MNR effluent water quality it was not possible to determine KPIs in terms of flux, energy consumption for the membrane systems. Quality parameters were at or above expectations after membrane filtration. For example, the conductivity reduction rate was 95%. The turbidity reduction rate was 25%. The COD reduction is equal to 90%.

Protein production from wastewater

At the La Trappe brewery demo case, a photobioreactor was demonstrated to treat brewery wastewater and urine in a mainstream to produce proteins that can be used as a slow release fertiliser. In general, this technology is also capable to produce proteins that can be used as fodder or even food additive. The TRL of the technology is still low between 5 and 6 and further

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investigations are needed. The recovery rates were 38% for COD, 20% for N and 25% for P. The photobioreactor produced roughly 0.48 g TSS biomass per litre wastewater. This corresponds to a production of around 276 to 575 kg of dried biomass per year to be used as a slow-release fertiliser. In NextGen, the proteins were successfully tested as a slow release fertiliser to grow microgreens. Furthermore, this technology is also very well suited to treat concentrates from membrane treatments.

Summary of solutions and main outcomes for La Trappe

Subtasks	NextGen solutions	TRL	Capacity	Product	Quantifiable target
Sub-Task 1.2.6	Metabolic network reactor (MNR - plant root enhanced fixed bed bioreactor) + MELiSSA advanced separation systems (UF/RO or NF) to produce fit-for-purpose water	MNR - plant root enhanced fixed bed bioreactor (TRL 7 → 9) +	100 L/h	Reclaimed water for bottles washing, aeroponics and aquaculture	Recovery rate: MNR: 99%, MF/RO: 20-30%
Sub-task 1.4.4	Photobioreactor and "Bio-makery" for carbon, nitrogen and P-recovery	TRL 4 → 6	60 L/d	Proteins as slow release fertiliser for food production in conditionised growing systems	COD: 38%; N: 20%; P: 25%

Gotland

The need for alternative water supply solutions at Gotland is related to increased population, increased tourism, increased need for irrigation, and the effects of climate change. Due to the flat landscape, relatively few lakes, the tin soil and the solid lime rock underneath, the possibilities for storing water from the wet winter to the dry summer is highly limited. This is especially true for the peninsula Storsudret, which is probably the most challenging part of Sweden in terms of water supply. The solution, so far, has been to invest in a larger desalination plant 45 kilometres north of Storsudret. The freshwater produced by the desalination plant becomes sewage after use. However, the wastewater treatment plant at Storsudret is not online, therefore the sewage is pumped 25 km north to a centralized WWTP, and then returned to the sea, where it mixes with chlorides which must be separated prior to processing in the desalination plant. If the sewage could be reused prior to being mixed with chlorides, the energy required for desalination would decrease. In addition, energy for long distance pumping could also be reduced if the sewage could be treated closer to where it is produced. Therefore, development of an energy efficient and local, direct reuse of sewage is highly attractive. The aim of the case study Gotland at testbed Storsudret is to show how a region with low ability to store water for the long, dry summer season could be a net producer of fresh water. The testbed will demonstrate how water could be collected, stored, reused, and infiltrated to feed the municipal water supply system, and be reused in real estate and irrigation of crops and grass.

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Applied solutions

Decentralised membrane treatment

Without the NextGen solution for sewage treatment, no water would be reused. How much water could be recovered as a percentage of the treated flow is a key parameter for evaluating the direct potable reuse from municipal sewage. During the early pilot tests in Burgsvik, there was little impact related to a high recovery rate. This is positive since a higher recovery rate results in reuse of more wastewater for irrigation, infiltration to the groundwater water, or other uses. The tests indicate that the recovery rate for the UF RO combination could be at least 80 %. The higher the recovery rate, the smaller the concentrate volume. At a recovery rate of 80 % the retentate will be 20 % of the original sewage volume, which reduces energy for pumping the concentrate, improves the efficiency for biological treatment (e.g. by anaerobic USAB technology), and improves nutrient recovery efficiency. Anaerobic treatment of the concentrate is estimated to lower the energy consumption by > 50 % compared to conventional aerobic wastewater treatment. Additionally, the biogas yield should almost double. The KPIs for reused water quality compare the RO permeate quality with the Swedish drinking water standard.

Innovative floodgate for storage of rainwater

Mjölhatteträsk is an example of where a ditching carried out during the 1950s lowered the lake to make use of previously soaked areas for arable land and grazing. Here, modelling has shown that recreating the previous level (about 20 cm higher than today's maximum level) would mean that just over an additional 200 000 m3 of water can be stored in the lake and would make a good contribution for a full-scale test bed that can produce 500 000 m3 of water for Gotland's drinking water network. The implementation of an innovative floodgate for rainwater harvesting was evaluated to quantify the water savings, in terms of drinking water demand. The study shown that more than 100,000 m3 should be able to be stored in the lake and without the floodgate, this volume of fresh water would have flowed into the Baltic Sea via the ditch.

Real time measurements of the water balance

The Gotland study evaluated the same catchment surface and water storage as in the rainwater harvesting system. Based on the results of the water balance measurements for Storsudret and the use of the systems, it was shown a system which could produce 450,000 m3 of drinking water and 100,000 m3 of irrigation water annually. Half of the annual drinking water supply would take place during the critical supply period from May to October. Irrigation water could be produced through collecting and storing rainwater to ensure the continued local commitment to the case study area Storsudret, which so far has been very large.

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Summary of solutions and main outcomes for Gotland

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<tr><td rowspan="3">Sub-Task 1.2.1</td><td>Real time measurements of the water balance; precipitation, flow in ditches, surface- and groundwater levels.</td><td>8</td><td rowspan="2">100 000 m^3/y</td><td rowspan="2">Urban and agricultural uses</td><td rowspan="2">25% of saving of drinking water demand</td></tr>
<tr><td>Innovative floodgate for storage of rainwater in a lake</td><td>8</td></tr>
<tr><td>Direct membrane filtration of sewage</td><td>6</td><td>1.6 m3/h</td><td>Indirect drinking water supply according to Swedish regulations SLVFS 2001:30</td><td>Drinkable water. Recovery of 75%</td></tr>
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Athens Urban Tree Nursery

The Athens Urban Tree Nursery demo case (EL) focuses on the demonstration of innovative concepts of alternative water sources to reduce the use of freshwater resources, as well as integrated energy and nutrient recovery technologies on the transition to a CE-based water sector. In particular, the scope of the Athens pilot is to produce recycled water from urban wastewater with a sewer mining modular unit for urban green irrigation and other non-potable uses at the point of demand. The Athens Tree Nursery comprises 4 ha of vegetation and supplies all urban parks and green spaces of Athens with plant material and uses potable water from Athens's Water Supply and Sewerage Company (EYDAP) for its irrigation. Thus, the installation of a sewer mining (SM) modular unit for urban green irrigation at the point of demand has proven to be of direct benefit for the sustainability of the new metropolitan park of the capital. In particular, the SM technology is a decentralised, flexible and autonomous CE solution in which wastewater can be extracted locally from the sewers that run under any city, be treated directly on site and create valuable high quality reused water at the point of demand to be used for green spaces irrigation and for aquifer recharge during the winter.
Furthermore, the site was an ad hoc storage area for pruning waste from park maintenance activities across the city. Thus, the installation of a rapid composting technology in the site using excess dewatered sludge produced from the SM unit and treated pruning wastes from the nursery, is of direct benefit for the sustainability of the area. In particular, these two components (prunning and sludge) are being continuously mixed in a Rapid Composting Bioreactor, where the closed and aerated system speeds up the degradation process to create in approximately 2 weeks roughly 200 kg of high-quality compost as an on-site fertilizer to be applied on the place of demand (Nursery plants). In addition to water and nutrient recovery, a thermal recovery unit is also installed at the site to test energy recovery schemes through a heat exchanger and heat pump system, recovering approximately 15kWh of thermal energy from the treated wastewater. This heat is used to boost the Rapid Composting Bioreactor, for added system efficiency.

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The overall goal is to create healthy and vibrant green spaces in the city of Athens. The pilot test shows that by upcycling two available waste streams: wastewater (& sludge) and green waste, Athens can have a sustainable solution for irrigation water and nutrient rich compost.

Applied solutions

Membrane bioreactor sewer mining unit

The membrane bioreactor (MBR) unit has the innovative advantage of an automated ICT system with pneumatic actuated valves controlled by a PLC unit, which allows continuous control and monitoring of the sewer mining unit by uploading data to an online system. The quality of the process and the effluent is controlled by a series of online sensors installed at several key points of the unit which provide perpetual information about the integrity of the operation. Conductivity meters were installed in the inlet and permeate tank, pH sensors in the membrane tank, a turbidity sensor in the permeate tank, an MLSS sensor in the membrane tank, a DO sensor in the aeration tank, and finally a nitrate and ammonium sensor in both the anoxic and aeration tanks. Before the implementation of NextGen in the baseline scenario, the municipality of Athens had been irrigating the nursery with potable water, brought in by EYDAP from more than 250Km away at great cost. The results of NextGen project led to the conclusion that the installed MBR/UV pilot unit can produce water of excellent quality in line with the standards specified in the Greek National legislation regarding wastewater reuse for unrestricted irrigation and urban reuse.

Thermal energy recovery via heat exchanger and heat pump system

The Athens demo case demonstrated a small-scale combined heat exchanger and heat pump system to use available excess heat from treated wastewater produced from a sewer mining unit as an energy source. Wastewater thermal energy recovery was successful scaled down from MW to kW scale using clean treated wastewater and commercially available heat pump making decentralised energy recovery technically and commercially feasible which also can be simple to operate. The small-scale heat recovery system demonstrated in the Athens site was set up in the 1-10 kW range. Thus, this resulted in acceptable system efficiencies with coefficient of performance (COP) values in the range of 4.0-5.12 in the heating mode and energy efficiency ratio (EER) values between 3 and 4.85 in the cooling mode. Although these values were lower than the typical values, 4.4-8.25 for COP heating mode and 6.5-6.9 for EER cooling mode, the system had less biofouling potential due to the fact that the system used the treated wastewater as the source of thermal energy. In addition, considering a full-scale decentralized system (250 m3/d irrigation water) the net recoverable thermal energy (heat pump energy use deducted) can be as much as 230 MWh/year. More than 67% of this energy recovery can be credited and used for general heating and/or cooling purposes (the remaining 33% is used for composting/nutrient recovery boosting). However, more studies on long-term operation under various feed quality conditions are required to improve its transferability and scalability as a sustainable urban water-energy solution.

Rapid compost production

In the sewer mining unit of Athens, the excess sludge from the membrane bioreactor was thickened and together with pruning waste composted in a rapid composting bioreactor. The yearly produced amount of compost was 5 t, which was reused on-site. An upscaled system referring to 600 population equivalents (PE) has the potential to produce 1 t N/a and 0.34 t P/a. This corresponds to 15% and 72% of the N and P loads in the raw wastewater.

Summary of solutions and main outcomes for Athens

Subtasks	NextGen solution	TRL	Capacity	Product	Quantifiable target
Sub-Task 1.2.4	Membrane bioreactor (sewer mining unit)	TRL 6 → 8	Water produced 25 m^3/d	Reclaimed water for urban irrigation and other non-potable uses according to Greek legislation 354/8-3-2011	Reclaimed water production of a 99% recovery
Sub-Task 1.3.4	Heat exchanger and heat pump	TRL 6 → 7	10 kW	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
Sub-Task 1.4.10	Rapid composting unit	TRL 7	5 t compost/a; 600 PE: 1 t N/a & 0.34 t P/a	Compost	Recovery: C: 60%, N:80%, P: 100%;

Filton Airfield

The former Filton Airfield has been recognised as one of the most important brownfield development opportunities in the UK. The 143-ha site is located in the Bristol northern fringe. A master plan for this site includes providing live and work opportunities and an efficient traffic and transport network. In addition, a 17 000-seat venue at the Brabazon Hangars will be built within the existing structure on the edge of the former Filton Airfield.

Within NextGen, water and energy management will be further developed and implemented as part of this masterplan. For water circularity, the activities include the development of a sustainable urban drainage system, rainwater harvesting demonstration. In addition, the feasibility of heat recovery from the sewer system for local heating will be investigated.

<u>Applied solutions</u>

Rainwater harvesting systems at district level

In Filton Airfield, the NextGen solution for water reuse considered a rainwater harvesting system consisting of a catchment area, conveyance system, storage system, and distribution system. In terms of rainwater recovery, the relevant KPIs were: (1) the real rainfall measurement and (2) the amount for proper purposes. The historical collected data was used to demonstrate a rainwater harvesting system in Filton Airfield. The baseline situation refers

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to the existing cases implemented in the UK and has offered some solutions to determine the optimum storage capacity for utilising rainwater harvesting at residential or commercial buildings by considering optimizing variables, including cost, reliability, water saving efficiency, green roofs irrigation and runoff capture. From several theoretical scenarios varying the catchment surface between 13 000 - 30 000 m2, it was estimated that installing a system such as it is possible to reduce 10-75 % of drinking water demand when using the harvested rainwater for toilet flushing and public irrigation in the area.

Feasibility study of low-grade heat recovery potential

A feasibility study was conducted on low-grade heat recovery from wastewater using a simulation-based approach analysing the potential of energy savings based on wastewater flow and temperature profiles. Housing units generating a large amount of wastewater held significant potential for energy recovery. The results showed that if the wastewater discharge is cooled by 3 °C for heat recovery, it is possible to recover up to 38 788 kWh/y (i.e., 7.85% of the total energy demand for the study area) for the residential area consisting of conventional houses, indicating that the total heat recovery potential is highly dependent on wastewater flow rates. In the frame of the Filton Airfield development, a decentralized and compact heat recovery system (i.e., a combination of a heat pump and heat exchanger demonstrated in Athens) would be one of the favourable solutions to increase self-energy efficiency if considering treated wastewater as a heat recovery source.

Dynamic sewer modelling: impact of low-flow wastewater on nutrient concentrations

In Filton Airfield, a circular economy concept shall be implemented on a regional scale in the near future. Therefore, the nutrient concentrations in the potential wastewater were modelled. An important aspect to consider thereby was the dependence of the nutrient concentrations on the type of housing and the installation of water-saving appliances. Using those, the wastewater flow rate decreases and contributes to higher nutrient concentrations in the potential wastewater. Hence, the changes of the nitrogen and phosphorus concentrations vary from 52% to 61% and from 27% to 42%, respectively, depending on the house type (ecohouse with water-saving appliances vs. conventional house). For Filton Airfield, the ion exchanger and the hollow fibre membrane contactor (see case study Spernal), are suggested to be the most appropriate and sustainable solution among the NextGen nutrient recovery technologies, because they can be applied as a decentralised system on a local level as required in Filton Airfield and they profit from a high nutrient concentration in the inflow stream.

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Summary of solutions and main outcomes for Filton Airfield

Subtasks	NextGen solutions	TRL	Capacity	Product	Quantifiable target
Sub-Task 1.2.7	Decentralized solutions for increased circularity in new housing districts	TRL 7 → 9	10 - 600 m^3 storage capacity, depending on applications (residential or commercial)	Toilet flushing and public irrigation	Theoretical study; 10 – 75 % of water savings per year
Sub-Task 1.3.1	Decentralized energy recovery and usage from anaerobic MBR	TRL 9	113 houses	Energy reuse within the WWTP or export of electricity or biomethane to grid.	200 m3/day; Electricity & heat produced for the two scenarios: 1.CHP-electricity and heat: 44 kWh/day and ~ 50kWh heat/d (assuming around 15% losses) 2. Biogas upgrading: 108 kWh/d
Sub-Task 1.4.9	Decentralised nutrient recovery solutions for increased circularity in new housing districts	TRL 9	113 housing units	Nutrients	Flow rates decrease between 49 and 55 % Nitrogen concentrations increase 52% - 61% Phosphorus concentrations increase 27% - 42%

Timisoara

The Timisoara water system is operated by AQUATIM SA (public company). The regional utility is offering services for drinking water (28 water treatment plants) and operate regional wastewater treatment plants (22 in their area) as well as leakage reductions in the distribution systems. The Timisoara biological waste water treatment plant includes the nitrification-denitrification process and the chemical treatment for the removal of phosphor. The excess sludge is stored in tanks, thickened and dewatered with polyelectrolytes. In NextGen, the project will tackle the thermochemical conversion of sewage sludge and will study the water reuse for several industries in Timisoara. At the Timisoara WWTP, pilot-scale testing of thermochemical conversion of sludge will be implemented. The technology demonstrated will be pyrolysis (via thermo-catalytic reforming) of aerobically stabilised sewage sludge to produce biochar, oil and gas. These products can be exploited energetically as fuel or soil enhancing agent or sorbent. The water reuse of the secondary effluent of the Timisoara WWTP will be studied, looking into the feasibility for urban (e.g. street cleaning, park irrigation), industrial and agricultural (farm land irrigation) applications. For the water re-use study, the local project partners mapped potential users by performing a water demand analysis of municipality, industrial and agricultural users, described the water quality issues related to sectoral water reuse and suggest treatment options, and assessed the different environmental and economic/financial implications that could result from water re-use.

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Applied solutions

Feasibility study on reclaimed water production at regional level

The study of water reuse in the Timişoara Metropolitan area shows that a more profound cost-benefit analysis understanding of the economic viability and opportunity of water reuse systems is needed. The involvement of various stakeholders available locally is also important, along with understanding the capacity of water resources management and societal involvement. Even though water reuse is currently implemented in some European countries, water reuse projects will only succeed in Romania if water-related and industrial authorities along with users will understand and apply the Integrated Water Resources Management concept. The three cases investigated showed that wastewater reuse is not easy to implement in the current way of placing the WWTPs - downstream and outside settlements. The cost of return the reclaimed water back in the city/localities is going to be too high due to the pumping needed. Also, returning reclaimed water back where would be needed requires expensive solutions to cross the city old area.

Prior to implementing circular economy solutions for water recovery at full-scale and at a local or regional revel, it is recommended to conduct a feasibility evaluation. The study carried out in Timişoara also integrated potential stakeholders which could benefit from the implementation of advanced treatments for the wastewater in order to obtain the reclaimed water for reuse, established collaboration with the local and regional administration, and conducted dissemination and communication activities to increase the knowledge and awareness on water scarcity, water reuse and circular economy. The study focused on recovering 100% of the current WWTP effluent (10 800 m3/h). Three clients for reclaimed water use, as well as the cost to build the reclaimed water distribution network and the water quality required for the selected uses, were identified.

Biochar, oil and gas production via sludge pyrolysis

In Timișoara, a pyrolysis process was tested as a side stream treatment of dried digestate to produce pyrolysis gas, oil as well as biochar. The recovery rate was 18% gas, 2% oil and 63% biochar. The pyrolysis batch experiments with the sludge originating from Timișoara showed a potential to substitute around 3100 m^3 natural gas/d with an up-scaled system.

Summary of solutions and main outcomes for Timișoara

Subtasks	NextGen solution	TRL	Capacity	Product	Quantifiable target
Sub-Task 1.2.5	Study of potential water reuse	4	250,000 m3/d Secondary effluent	Urban, industrial and agricultural use	Theoretical study; 10 800 m^3/h
Sub-task 1.4.6	Pyrolysis for the production of oil/char/gas	4	2.1 kg dried sludge/h; 400 000 PE: 3100 m^3 gas/d	Gas, oil and char	Recovery: 18% gas, 63% char, 2% oil

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