NEXTGEN: a Serious Game showcasing circular economy in the urban water cycle.

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Abstract

Understanding the Circular Economy for water is challenging. It requires being acquainted with the individual components involved in the urban water cycle such as stormwater, water conveyance, groundwater, water drainage, wastewater treatment and discharge. In addition, to appreciate benefits and tradeoffs in the context of Circular Economy, one also needs to factor the interrelations between water and other factors such as material recovery, energy use, expenses, and environmental impacts. On top of it, the fact that each catchment has a different geography, hydrology and urban setup can lead to difficulties in transferring gathered knowledge to other situations. In response to this challenge of developing a holistic understanding of applying Circular Economy to the urban water cycle, the NextGen Serious Game has been created. It is a simulation based online educational tool with a digital user interface that allows participants to explore the implications of applying circular economy strategies such as “Reduce” (for waste), Reuse (for materials), and Recovery (of energy though biogas generation) to the water urban cycle in different virtual catchments representing different settings. 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 serious game was successfully used as a teaching tool in student classrooms (leading to an average improvement of about 26% in the number of correct answers). Furthermore, it made an effective debate facilitation tool contributing to the discussion of a multi-disciplinary expert panel by bringing new insights to the discussion. Finally, the Serious Game was used to organize the first e-sport competitive tournament between water professionals at an industry conference, paving the way for a novel form of engagement. This is a considerable contribution to public understanding at a time where the water industry struggles to sensitize a wider audience to the problems and reality of water in the context of climate change, growing resources scarcity, and environmental decline.

Keywords

Circular Economy for Water; Serious Gaming; Urban Water Cycle; Material Reuse; System Dynamics Model.

1. Introduction

In contrast with the natural regional hydrological cycle that focuses on environmental condensation, precipitation and evaporation, the urban water cycle focuses on how human activity changes stormwater intake, water conveyance, groundwater use, water drainage, wastewater treatment and discharge. As an anthropogenic water cycle, it can be easily associated with “Circular Economy”, itself defined by The Ellen MacArthur Foundation (2010) as a “systematic approach to development designed to benefit businesses, society, and the environment.” It relies on three principles to decouple growth from the consumption of infinite resources: reducing waste and pollution, reusing products and materials, and the regeneration of natural systems. When applied to the urban water cycle, it becomes a complex multidisciplinary endeavour that demands in-depth knowledge of interconnections between areas such as wastewater treatment, energy and water management, environmental health, and material reuse. Helping a general audience to understand how changes in the urban water cycle can facilitate the achievement of circular economy goals can therefore be a challenging task. This paper describes the work undertaken within the Horizon 2020 NextGen research project (NextGen Water, 2022) to respond to this challenge: a Serious Game taking the shape of a simulation based online educational tool designed to engage all types of stakeholders including citizens, businesses, and policy makers on the topic of Circular Economy for Water.

Serious Games were introduced by Abt (1970) as “games used for purposes other than mere entertainment”. Now viewed as an integral part of Simulation based Education (SE), they have taken advantage in substantial advances in the field of computing to allow innovative methodologies to be applied for educational purposes, decisions support, and public policy making (Campos et al., 2020). Many Serious Games have been developed on the topic of sustainability (Katsaliaki and Mustafee, 2012; Stanitsas et al., 2019) as a broad concept related to people, the planet, and the economy. Regarding the related and more specific concept of Circular Economy, there is evidence of a smaller body of work (De la Torre et al., 2021) with an emphasis on resource management, individual economic benefits through input reduction, efficiency gains, waste avoidance and reduction of environmental impacts. There are examples of serious board games focusing on material criticality ("In the loop" - Whalen et al., 2018) and mostly energy transition toward sustainable generation (with the examples of Energy Safari (Gugerell and Zuidema,2017) and Energy Transition Game (2020) with an emphasis on role playing. Digital Serious gaming is being applied to topics such as the impact of renewable energy policies on carbon emissions (Climate Change Serious Game, 2020), the economic, environmental and security trade-offs and opportunities associated with different energy sources (Energyville, 2020), energy conservation for householders (Encon City - Stanitsas et al., 2019), and industrial training to support sustainable practice (Rai and Beck, 2017). Although Serious Games on Circular Economy do often mention and include water as an important of part of the problem, they do not, to our knowledge show in a cohesive way how combinations of components inside the urban water cycle such as households' water reuse technologies can have for example a major impact on water stress, energy use, and water quality; how wastewater treatment technologies like biogas generation and sewer mining can lower carbon emissions; and how nature-based solutions such as sustainable drainage systems can deliver cost-effective ways to limit discharges of untreated water into rivers. Similarly, although surveys looking at the use of Serious Gaming in the domain of water (Savic et al., 2016; Mittal et al., 2022) show a focus on the management of water systems (Savic et al., 2016; Geneva Water Hub, 2016; Games at the World Water Day, 2015; Tygron Engine, 2016, Susnik et al, 2018), flood and drought prevention (Rijcken and Christopher, 2013; Khoury et al., 2018; Hill et al., 2014), training for emergency response (Wang and Davies, 2015; De Kleermaeker et al., 2011; De Kleermaeker et al., 2012), and conflict resolution (Seibert and Vis, 2012), there is no systematic emphasis on a link to Circular Economy. This work aims at bridging this gap by introducing a serious game that aims to raise public awareness of circular economy for water, to increase understanding of the interactions between different components of the urban water cycle in circular economy, and to facilitate the dialogues between different stakeholders to reach consensus in decision making.

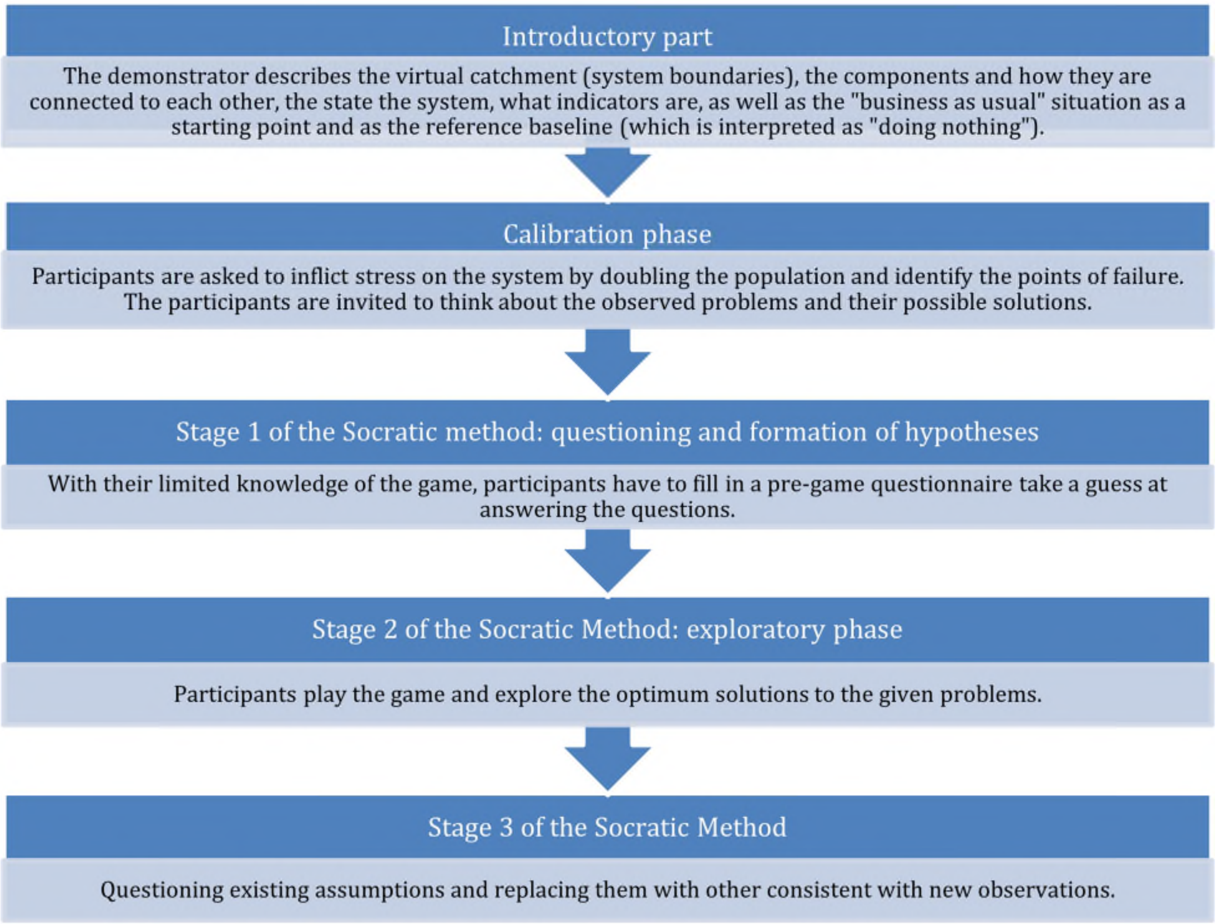
The learning methodology in use combines a pedagogically driven design that gently introduces participants to the relevant concepts in an interactive way based on constructivism (Devries and Zan, 2003) (where learners take an active role constructive knowledge by “doing”) and experiential learning (Kolb, 1984; Angehrn and Maxwell, 2009) (where experience leads to the formulation of hypotheses and then their validation). Furthermore, building on previous work (Khoury et al., 2018) that incorporates the Socratic method (Hunnicutt, 1990), participants are prompted to question some of their own assumptions and replace them with more sound alternatives uncovered while exploring the serious game. In this paper, we will first discuss the conceptual design, and then look at the implementation. Finally, we will analyze the results and discuss further work in conclusion.

2. Conceptual design

The Serious Game aims at enabling both experts and neophytes to reach three sequential goals: goal one - understand the building blocks of the urban water cycle; goal two - discover the influence of external factors such as rainfall and population growth; goal three - discover what actions lead to minimising stress on the system and maximising circular economy. Furthermore, basic concepts of the urban water cycle need to be made clear and easy to explore for the benefit of the general public while introducing specific facts from different disciplines for the benefit of experts (typically, water, energy, or environmental sciences professionals will be offered interesting insights that can only be gathered from running the model - for example, how installing a fog shower in every household can reduce the overall energy footprint for water usage inside the virtual catchment by up to around 30%).

2.1. Learning methodology

Concretely, in order to reach these three learning goals, the Serious Game implements the following five-stage hybrid learning methodology (as shown in **Figure 1**) extending work done by Khoury et al. (2018):



Introductory part

The demonstrator describes the virtual catchment (system boundaries), the components and how they are connected to each other, the state the system, what indicators are, as well as the "business as usual" situation as a starting point and as the reference baseline (which is interpreted as "doing nothing").

Calibration phase

Participants are asked to inflict stress on the system by doubling the population and identify the points of failure. The participants are invited to think about the observed problems and their possible solutions.

Stage 1 of the Socratic method: questioning and formation of hypotheses

With their limited knowledge of the game, participants have to fill in a pre-game questionnaire take a guess at answering the questions.

Stage 2 of the Socratic Method: exploratory phase

Participants play the game and explore the optimum solutions to the given problems.

Stage 3 of the Socratic Method

Questioning existing assumptions and replacing them with other consistent with new observations.

Figure 1. The serious game uses a five-stage hybrid learning methodology mixing constructivist experiential learning (introduction followed by a calibration phase) and the disruptive three-stages Socratic method.

- The introductory phase contributes to the first learning goal where users are shown the building blocks of the urban water cycle. The water resources are first identified (municipal water supply and precipitation) in a virtual catchment. Elements that cover the distribution, storage, use, collection, treatment, and the discharge of stormwater and wastewater are identified. The model behind the game simplifies the representation of soil types and conditions with an “infiltration rate” parameter for pervious areas and a runoff coefficient for impervious areas. For example, some urban surface mixing permeable pavements and home lawns could have a typical infiltration rate of around 90mm/hour. Although the Toy Town model itself does not consider pipeline leakages nor groundwater recharge facilities, one of the case studies (the Costa Brava version) has a simplified representation of groundwater recharge and extraction as part of its Aquifer management game feature. The system is shown in its default starting state (akin to a “business as usual” situation) and game score indicators tend to show minor water and environmental stress, as well as an average Circular Economy health score.

- The calibration phase contributes to the second learning goal. Different initial states corresponding to different typical crisis scenarios are simulated. For example, the demonstrator suggests observing the consequences of doubling the population and reducing rainfall. Points of failure are then identified in front of the whole group: the demonstrator shows the system not being able to meet the town water demand, the town reservoir being constantly stressed, the environmental flow reduced, thereby threatening the balance of the river ecosystem, and the water quality in the river downstream being poor. Emphasis is put on the fact that water is not an infinite resource, and that the urban water cycle is a system on edge that can easily break down. It is then suggested to the players that they will have to explore how they can improve the situation, by trying combinations of measures and playing the game.
- In stage 1 of the Socratic method, participants must fill in a pre-game questionnaire. This is the beginning of a series of steps aiming to help participants to achieve their third learning goal. They are asked to answer multiple choice questions and therefore are guided towards validating some of the hypotheses implied by the different possible answers. In other words, with their limited knowledge of the game, they have first to guess what the best possible initial set of measures is that will improve the Circular Economy score.
- Stage 2 of the Socratic method is an exploratory phase. Participants are asked to improve the overall Circular Economy score while minimizing some additional requirements, e.g., making sure that the town water demand is always met at 100% and that pollution stays below a certain threshold. This phase requires players to actively experiment with the components and how they can be connected, to find the combinations of factors leading to the worst and best outcomes, respectively. While doing so, they will stumble upon answers to the questions asked previously and will need to think about them and “act” within the game.
- Stage 3 of the Socratic method capitalizes on the previous explorative work. Participants must fill in a post-game questionnaire identical to the first one. As the participants answer based on their experience playing the game, they are brought to question their initial assumptions and replace them with new ones based on model outcomes.

Having chosen a methodology, the next challenge is to find out what aspects of real-world problems to include in the Serious Game.

2.2. Choosing what real-world problems need to be included in the Serious Game

The game models a virtual urban catchment named “Toy Town” built to be representative of many common medium-sized towns. From a scale point of view, the catchment area is 314 square kilometers (roughly one fifth of the size of London), with a population of around 300,000 inhabitants. The catchment features a reservoir fed by a river that ultimately flows into the sea. Rainfall patterns represent the typical hydrological characteristics of a Mediterranean area, with seasonal fluctuations (concentrated rainfall in the autumn/winter and long dry periods in the summer). Water demand, energy footprint, and water quality downstream are influenced by the incorporation of water-saving and reuse technologies within households and the ability to connect runoff and wastewater to sustainable drainage systems and secondary wastewater treatment plants. A system dynamics model, running behind the game, as a computational engine, captures how water flows throughout the urban catchment via the water supply, stormwater, and wastewater systems. The model is designed to capture the following real-world problems:

- Water supply problems are considered by allowing scenarios to start with a lowered rainfall or a depleted reservoir, or by allowing the user to change these parameters. Rainfall has an immediate impact on the ability to satisfy water demand and to maintain river flow. Heavy rainfalls also have the capacity to overwhelm wastewater treatment and can lead to uncontrolled discharges of untreated water.
- The impact of water use is analysed by changing the size of the population, and the type of devices and technologies in use in selected groups of households. The population is the main driver behind water and energy demand, as well as a determining factor behind the volume and the toxicity of the sludge generated by the town. The choice of devices in use in households can drastically impact the energy footprint linked to water use at the catchment level as well as the associated carbon emissions.
- The effects of variations in the water storage management are covered by allowing users to change the settings of diverse types of reservoirs (ranging from the main town reservoir to sustainable urban drainage systems). These are control systems with non-linear behaviours that require some measure of careful exploration to optimise.

- Changes in the collection of stormwater and greywater (the wastewater that comes from sinks, washing machines, bathtubs and showers) as well as the collection of black water (wastewater from bathrooms and toilets that contains fecal matter and urine) can have various impacts on the system.
- Diverse types of water treatments are considered. Parameters allow the activation and regulation of local household-based treatment (for rainwater and greywater reuse), as well as the management of the primary and secondary wastewater treatment plants. These settings can influence water quality downstream in the river and change energy savings and carbon emissions associated with material reuse and biogas generation.
- The discharge of treated and untreated wastewater is affected directly by the volume of runoff water as well as the wastewater treatment capacity. When the user indirectly changes these factors, the water quality in the river is impacted noticeably.
- Finances are impacted by the diverse types of technologies in use due to installation and operational costs.

2.3. Game components and connections between them

To improve usability and readability for end users, only the components that give the most important information from both an urban water cycle perspective and a circular economy point of view are shown in the game (see **Figure 2**). The goal is primarily to help the users to understand how changing the interactions between the urban water cycle components can help with alleviating stress on the system and achieving some circular economy goals. As such, the water-related components that the player can change and monitor need to be first and foremost clearly identified. The flow of water between these components is also visually depicted. Our design choice was to focus on helping the players remember a mental map of what component can be changed (for example using sustainable drainage systems, and grey water reuse technology in households) and what kind of effects these changes have on the visible indicators.

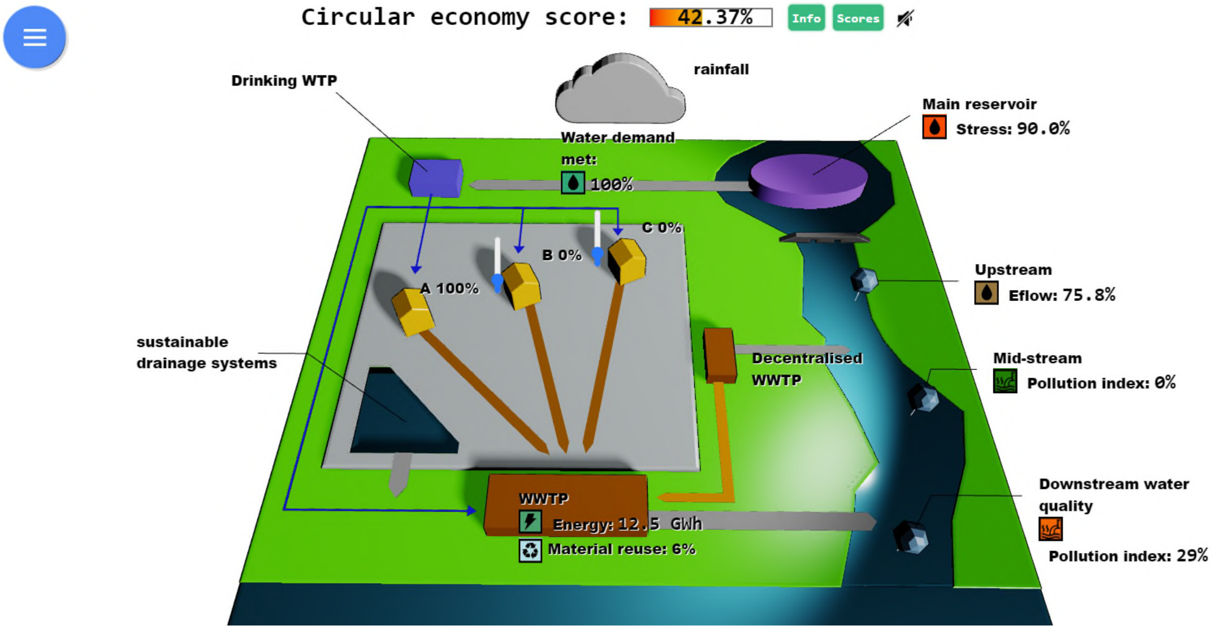


Figure 2. Screenshot of the serious game showing selected urban water cycle components.

"Toy Town" is a refined and user-friendly representation of a virtual catchment presenting only the most essential components for monitoring the urban water cycle and at the same time considering circular economy. From a practical point of view, these components are chosen based on the following criteria:

1- the chosen component is essential to understand the water urban cycle. For example, households are the main predictor behind water consumption and wastewater production, and without them, it would not be possible to understand what happens to water in urban environments.

2- the chosen component, when acted upon, lead to a significant change in the model output. For example, in the case of a water source like the reservoir, a small change to the discharge from the reservoir to the river can have a measurable effect on how water demand is met and at the same time can greatly affect the river ecosystem.

The selected components are the following:

- The reservoir that depends on rainfall to supply water for both human activity and the river ecosystem. Any measure of stress on the reservoir (here, the percentage of years where the reservoir stays below a certain threshold for a given number of days per year) will provide a useful indicator on water scarcity and its possible impact on town needs and natural ecosystems linked to the river.

- The households that make the urban environment (with indicators such as water demand met i.e. the volume of water supplied to the houses, which could be less than the actual water demand in case of water shortage; water-saving or reuse technologies, associated energy footprint, and financial costs). Households can be divided into three neighborhoods A, B, and C of varied sizes (sliders can adjust what percentage of the population they represent), and where different choices of technologies can be made regarding water use. The model behind Toy Town is a generic framework that can be expanded to accommodate neighborhoods with different characteristics. It is possible to change the characteristics of a residential neighborhood to fit other types such as a mixed-type land use neighborhood by adjusting parameters such as for example the average number of occupants per building, average roof area, the average garden size, the average roof tank capacity, the average roof rain capture coefficient.
- The river that contains indicators such as environmental flow (i.e. the amount of water left for the natural ecosystem of the river after subtracting water for supply the town) and water quality (using Chemical Oxygen Demand-COD as an indicator, where the pollution index represents the cumulative debt of oxygen resulting from the growth of algae fed by uncontrolled discharges of nutrients).
- The primary and secondary wastewater treatment plants (WWTP) use energy to treat water and reintroduce it into the river once up to standard. They sometimes release untreated water if their treatment capacity is overwhelmed by the volume of runoff in case of heavy rainfall. They also have the potential to be the center point of energy and material reuse practice that can significantly impact resource recovery in the context of circular economy.
- Sustainable drainage systems (SuDS): these nature-based solutions are small reservoirs that help retain or detain surface runoff from a site and prevent wastewater treatment sites from being overwhelmed by huge volumes of runoff water due to excess rainfall.

Because the emphasis is on simplicity, while still showing “hard” technical concepts (such as the mass balance of flows), it is essential to show how the individual components that make the urban water cycle connect and interact with each other. The connection between urban water cycle components has undergone a simplification following a process of co-design and users’ feedback resulting from consultations with experts and engineers whose expertise ranged from water systems, to modelling and policy. Different components of grey water reuse and rainwater harvesting treatment are hidden, while emphasis is put on connectivity. The user can see the resulting visual connections showing if households "greywater" is connected to SuDS or not. Similarly, the user can confirm at a glance if the households "black water" (the wastewater from bathrooms and toilets containing fecal matter and urine) is redirected to either a primary or a secondary WWTP (as shown in **Figure 2** schematic).

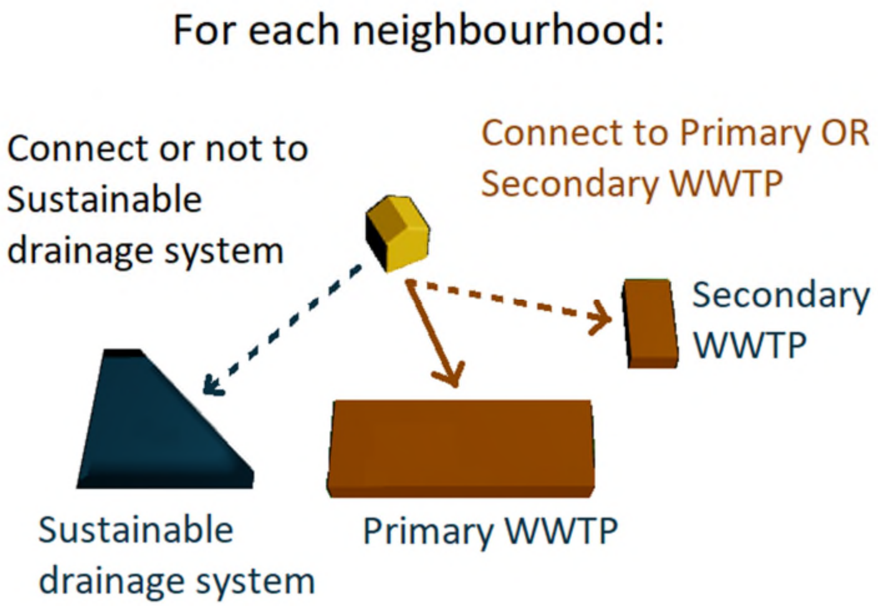
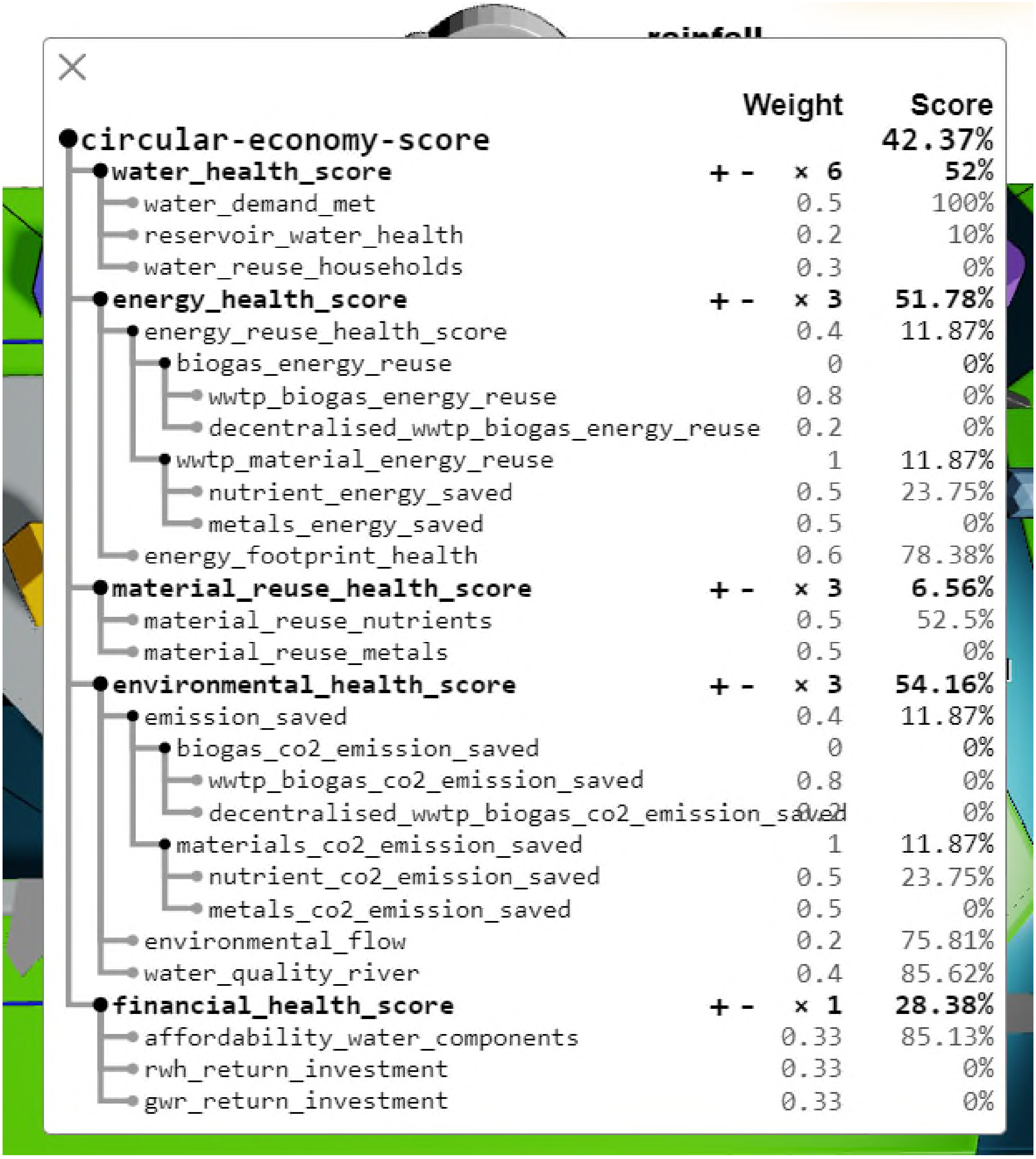


Figure 2: Schematic showing how households' greywater can be connected to sustainable drainage systems or not, and how the black water from households can be redirected to either a primary or a secondary WWTP

2.4. Game goals and participatory process

The goal of the game is simple and specific: to maximise the circular economy score at the very top of the screen (it is a weighted average of various Key Performance Indicators as shown in **Figure 3** - detailed table in appendix **A1**).



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                                                              Weight     Score
circular-economy-score                                                   42.37%
  water_health_score                                 + -       × 6         52%
    water_demand_met                                           0.5        100%
    reservoir_water_health                                     0.2         10%
    water_reuse_households                                     0.3          0%
  energy_health_score                                + -       × 3      51.78%
    energy_reuse_health_score                                  0.4      11.87%
      biogas_energy_reuse                                        0          0%
        wwtp_biogas_energy_reuse                               0.8          0%
        decentralised_wwtp_biogas_energy_reuse                 0.2          0%
      wwtp_material_energy_reuse                                 1      11.87%
        nutrient_energy_saved                                  0.5      23.75%
        metals_energy_saved                                    0.5          0%
    energy_footprint_health                                    0.6      78.38%
  material_reuse_health_score                        + -       × 3       6.56%
    material_reuse_nutrients                                   0.5       52.5%
    material_reuse_metals                                      0.5          0%
  environmental_health_score                         + -       × 3      54.16%
    emission_saved                                             0.4      11.87%
      biogas_co2_emission_saved                                  0          0%
        wwtp_biogas_co2_emission_saved                         0.8          0%
        decentralised_wwtp_biogas_co2_emission_saved           0.2          0%
      materials_co2_emission_saved                               1      11.87%
        nutrient_co2_emission_saved                            0.5      23.75%
        metals_co2_emission_saved                              0.5          0%
    environmental_flow                                         0.2      75.81%
    water_quality_river                                        0.4      85.62%
  financial_health_score                             + -       × 1      28.38%
    affordability_water_components                            0.33      85.13%
    rwh_return_investment                                     0.33          0%
    gwr_return_investment                                     0.33          0%
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Figure 3: Screenshot of all the KPIS that make the Circular Economy Score

Depending on the type of audience, the weights can be adjusted. For the NEXTGEN playing sessions, weights were adjusted based on feedback from water scientists to fit attitudes of an audience that would first prioritize the minimization of water stress (the water availability indicator was given a weight factor of 6), and then consider as a second priority indicators of energy consumption, material and energy reuse, and environmental health (all given a weight factor of 3). Finally, indicators of financial health were given the smallest weight (equal to 1). In practice, depending on the event and audience targeted, if there is a need to center the game around environmental problems, the environmental health score can be given a higher weight than all other scores. Participants face significant challenges such as overpopulation, water stress, elevated costs, poor water quality, a high energy footprint and resulting carbon emission. To maximise the circular economy score, players need to understand the roles of the different components and technologies and their influence on KPIs (Key Performance Indicators) regarding water availability, energy use, environmental impact, material reuse and costs.

The adequacy of the KPIs was appreciated first and foremost through the prism and feedback of water experts: priority was set on the water demand met, the reservoir stress, the environmental flow (as the amount of water left for the river aquatic ecosystem), and the water quality in the river expressed as a cumulative debt of oxygen measured from the concentration of nutrients discharged throughout time downstream and midstream. The financial indicators were also considered important as the suitability of a technology is linked to its cost (overall cost and return on investment period).

From then, after being able to appreciate which output variables were made available in the model, links to several circular economy strategies became apparent.

- Being able to quantify the water and energy footprint, and the amount of nutrients discharged in the river, KPIs linked to the circular economy “reduce” strategy could be identified. Firstly, “the reservoir stress” and “environmental flow” KPIs are quite sensitive measures strongly linked to water consumption. The later provides a measure of the environmental impact of excessive water subtraction on the river aquatic ecosystem. The “water quality” KPI is quite responsive to the combinations of water technologies adopted and relates to the discharge of untreated wastewater in the river. Reducing the amount of nutrients that end up in the river can affect environmental pollution. Minimising the “energy footprint” and by associated “carbon emissions” also have an impact on the “reduce” strategy.
- Other KPIs such as the estimated amount of “water reuse” in households and the degree of “material reuse” relate to the “reuse” circular economy strategy. Note that the “Water reuse score” in household is here given the meaning of the volume of greywater that is recycled over the total water demand. The greywater is

partially treated via helophyte filter and then reused for purposes such as gardening or toilet usage. “Material reuse” relates to quantity of the nutrients and metals extracted from the wastewater treatment plant inlet.

- Finally, the “Biogas energy reuse” KPI resulting from using an anaerobic wastewater treatment, maps to the “recovery” circular economy strategy where products that cannot be reused are turned into energy by incineration or other (bio-)chemical processes.

The game can be played as a single-player experience, or a competitive multi-player online event. Participants can submit their best solution and compare it with an online high-score table that is updated in real-time.

As a teaching tool, the serious game takes the form of supervised learning sessions with pre and post-game questionnaires (Shown in **appendix A9**) where understanding circular economy for water was narrowed down to making participants explore the game to try to answer seven questions. The answers to these questions reflect typical examples of technological combinations of measures that urban water systems that embrace circular economy would use. The questions were chosen to be sufficiently generic to be useful to a wide audience while fitting an hour-long training session:

- Players were asked in the first two questions to compare rainwater harvesting and greywater reuse technologies. Both technologies have different strengths and weaknesses and understanding the best way to use them is fundamental to resolve some of the issues posed by water scarcity and pollution. If installed at substantial cost inside all households, greywater reuse - independently from rainfall - can have the greatest impact on decreasing water stress. On the other hand, rainwater harvesting, can be an adequate and cost-effective solution to reduce both water stress and pollution downstream as long as rainfall remains sufficient.
- Users were then asked to compare the relative importance of the wastewater treatment energy footprint (2% of the total) with the energy footprint of households’ water-related devices (98%). This gave the participants a generic perspective regarding how engaging households can unlock the greatest potential for saving energy as opposed to wastewater treatment.
- Players were tasked with changing the behaviour related to the use of the reservoir to maximise the environmental flow in the river downstream. By manipulating two variables (the “baseline” and the “stress” discharge rate to the river), users can observe that the reservoir is a control system that oscillates between

stressed (or reduced discharge to the river) and normal modes (or greater discharge to the river). This is followed by a fairly generic but invaluable observation, namely that, in a control system, to minimise stress, there is need to know the particulars of the problem sufficiently, so as to be able to explore the whole solution space to find optimum solutions (which do not necessarily lie in extreme values).

- Participants were also asked to check what the effects are of connecting households to different components such as secondary wastewater treatment plant or a sustainable drainage system. In doing so, they had to realize that some technologies work particularly well together e.g. the option of adopting both greywater reuse and a connection to sustainable drainage systems is a potent combination to reduce both water stress and pollution downstream.
- Finally, the players had to determine whether harvesting of nutrients or metals from wastewater had the potential to save the most *exergy* (Calvo and Valero, 2017) (i.e., the energy that would be spent mining and refining these materials from scratch) and therefore contribute significantly to the overall circular economy score. This last question emphasizes the greater potential in terms of lowering carbon emissions of mining wastewater for rare and common metals (as opposed to only mining nutrients).

When the Serious Game is used inside a multi-player online competitive tournament, the participants' goal is to compete by solving two scenarios and by finding solutions with the highest possible score.

The first scenario, used as an introductory "warmup", refers to a situation where "Aquatech Town" is experiencing a prolonged period of extreme drought with rainfall being reduced by 50%. The mayor wishes to ensure that water demand is met 100% of the time via retrofitting neighbourhoods. Participants have to modify properties while maximizing the circular economy score, and make sure that the water demand met stays at 100%.

The second scenario is used for the tournament evaluation. A dramatic increase in the population of "Aquatech Town" coupled with a reduction in rainfall has put a significant strain on water resources. Water demand is met less than 50% of the time, environmental flows in the river are under 50% and there are high pollution values downstream. The mayor has released funding for modifying properties in a portion of the town called neighbourhood B representing 50% of all households. He is also calling for a review of the reservoir management (i.e. controlling the discharge parameters). Participants compete to find the best solution which involves maximising the circular economy score while making sure that the water demand met stays at 100%, the upstream environmental flow is greater than 70%, and the pollution index remains smaller than 20%.

3. Implementation

An online digital game translates into the need for a responsive interface that can deliver results to the player in real-time, and therefore implies an additional challenge in building a model that can output results from user queries fast, in under a second.

3.1. The modular and real-time simulation engine behind the game

The first modelling attempt behind "Toy Town" was initially based on the Urban Water Optioneering Tool (UWOT) model outlined for decentralised water solutions in the Dutch neighbourhood SUPERLOCAL and presented in Bouziotas et al. (2019). As the model grew in complexity and started to integrate more input variables, the number of possible outputs resulting from different combinations of input parameters grew exponentially. Beyond a certain threshold, the only way to deliver results in real-time is either to compute them on the fly or store them in some sort of database. As UWOT was not built to provide batch computation (where one would be able to compute multiple results in one run) nor to deliver results in real-time, it became necessary to consider building our own simulation engine. The NEXTGEN simulation engine was therefore specifically created to satisfy the following requirements:

- The simulation engine must be able to compute results in daily and sometimes hourly resolution, compact them in yearly format for the next twenty years, and send them in a timely fashion to the browser of the user, so that they can be visualized less than one second after pressing a button.
- The structure of the model must be modular, allowing the game to be easily extended and adapted to different case studies or situations (for example, allowing the addition of a desalination plant or an aquifer management component).
- The system dynamic model must be able to simulate water balance analysis and volumetric flows in the context of the urban water cycle in its core layer, but also be able to integrate an additional layer of computations related to circular economy that include elements such as material reuse, energy, carbon emissions, and finance as shown in **Figure 4**.

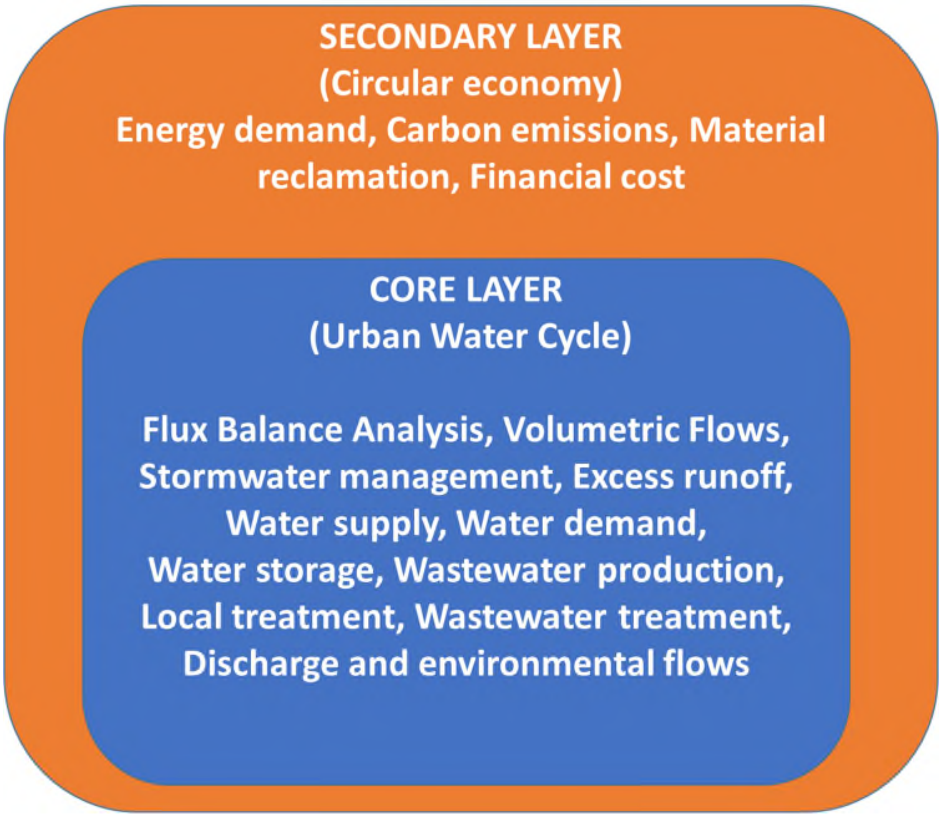
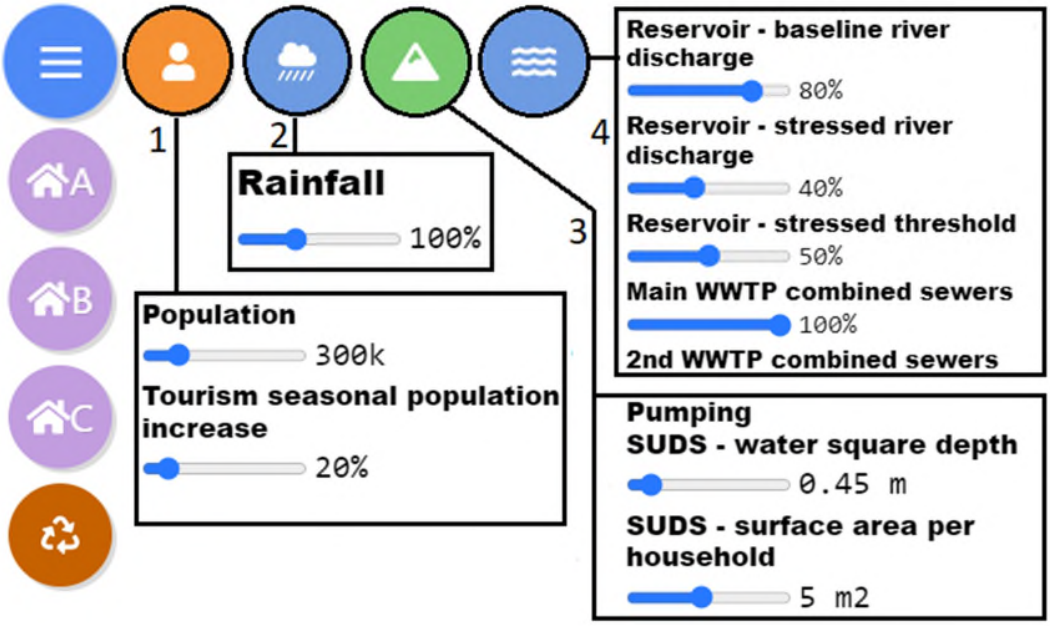


Figure 4: The layers of computational tasks behind the NEXTGEN simulation engine

After several subsequent iterative developments, the NEXTGEN System Dynamics Model was successfully implemented in the Julia programming language (Bezanson et al. 2012). The simulation engine takes 159 parameters as input and gives the corresponding results under the form of 163 lists of variables corresponding to outputs computed over 20 simulated years and does it quasi-instantly. It should be pointed out that the NEXTGEN simulation engine is fully detailed in the complementary article written for the same publication (Evans et al., 2022). The model was recently extended to accommodate different case studies. For example, an “Athens” instance of the model was built to focus on looking at the benefits of sewer mining for heat reuse as well as the production of fertilizer in tree nurseries. Similarly, a “Costa Brava” variation of the model is presently being finalised with an emphasis on a standard Mediterranean setting with an emphasis on aquifer management and the use of a desalination plant.

3.2. The user interface and the ranges of choices and actions available

The user can press a button on the top left of the screen to access at any moment a single radial menu (shown in the highlight **Appendix A2**) that contains all actions. Once deployed, the radial menu offers a choice of eight icons leading to different types of actions grouped by themes. Pressing the population icon will, for example, lead to sliders allowing to change the size of the population and the tourism seasonal population increase (thus directly influencing water demand and the resulting volume of wastewater). **Figure 5** shows the range of interactions triggered by the top four icons (population, rainfall, nature-based solutions, and the reservoir management), while **appendixes A3 and A4** show interactions for household related water use and wastewater related material recovery.



Rainfall 100%

Population 300k

Tourism seasonal population increase 20%

Reservoir - baseline river discharge 80%

Reservoir - stressed river discharge 40%

Reservoir - stressed threshold 50%

Main WWTP combined sewers 100%

2nd WWTP combined sewers

Pumping

SUDS - water square depth 0.45 m

SUDS - surface area per household 5 m2

Figure 5. Part of the interface allowing to changing the population size (1), rainfall (2), sustainable drainage systems capacity (3), reservoir management settings and degree to which sewers are combined (4).

The User Interface also provides rich visual information when clicking on indicators (as shown in **Appendixes A5 to A7**), as well as audio content (tracks containing detailed information automatically play pre-recorded explanations).

Players can change water technologies in use by the residents as well as the connection from the household's greywater and blackwater to nature-based solutions and primary and secondary wastewater treatment plants. The list of water saving technologies available to the user is quite comprehensive as shown in **Table 1.**

Table 1: list of household devices that users can experiment with.

Shower	A water saving shower is a shower featuring an efficiently designed nozzle, which reduces water use.

	A fog shower a shower with a water-saving nozzle that is activated in "mist"; or fog mode, drastically reducing water use.
	A recirculation shower feeds back water as you shower, reducing water use even further.
	A WTW or “Warmteterugwinning” shower (or heat recovery unit) is a shower with an easy drain heat exchange system that conserves energy.
Toilet	A vacuum toilet drastically reduces water use by introducing a pressure difference while flushing. It is fairly expensive, as the wastewater network of pipes needs to remain under vacuum pressure condition.
	A high pressure toilet employs a secondary tank to create additional air pressure and save water while flushing. It is less expensive to maintain than vacuum based systems.
	A dual flush toilet design introduces a dual flushing system; one low-water and one full flush, to match types of uses and save water.
	A water saving toilet is a smarter toilet design that uses multiple nozzles and centrifugal washing to ensure that water consumption remains low, while cleaning capacity is high.
	A compost toilet works by separating liquids from solids using two distinct tanks. It uses a minimal amount of water.
	Dry flush toilets are self-contained systems that are entirely waterless, but rely on chemicals and a mechanical system for flushing.
Sink	A water saving sink features water-saving nozzles that reduce water use per minute.
	A recirculation pump sink comes with an autonomous device that heats water upon demand. The recirculation pump saves a significant amount of water per year, as well as energy due to a more efficient heating of water.
Laundry	An eco-front loader washing machine utilizes lower temperatures, reduced load programs and the eco function. It can save a significant amount of water per wash.
Garden	A garden aeration hose will control the amount of water that flows through the tap without affecting the water pressure as it mixes the water with air.
	A garden drip irrigation is a micro irrigation system with small underground pipes that allow water to drip slowly to the roots of plants.

	A garden spray timer allows a greater control of the water quantities used to irrigate the garden.

3.3. Software architecture and deployment

The frontend of the game is a web page (the “client”) that interacts with a simulation engine running the System Dynamics model located remotely (the “server”) that delivers simulation results in real-time. The software infrastructure uses containerization – meaning that software code is packaged with all its necessary components and dependencies in a self-contained virtualized unit that can be easily moved around. The game can run as multiple server instances, scaling up with the number of players connected without any disruption to the service using Amazon “Elastic Container Service technology” (AWS Fargate, 2022). A direct consequence is that it is now possible to set up an online game session in a few minutes that could equally accommodate a group of 40 players, or a conference with 4000 participants! This flexibility has allowed the NextGen serious game to be used in various scenarios ranging from teaching students in a small classroom, to the animation of an online event gathering members of the public, to running a competitive e-sport tournament between experts at an international industrial water conference (Aquatech Innovation Forum, 2021).

4. Results

The Serious Game was used during three types of events: a supervised training session, a debate, and an e-sport tournament. The supervised teaching sessions involved a total of 44 participants and were the events that were concerned with gathering results. They were organized in early 2022 to gather information following the methodology described in **section 2.1** about how playing the game changed the players’ understanding of the Circular Economy for water problems by measuring differences in the way they answered the pre and a post-game questionnaires (**section 2.4** and **appendix A9)**. The figures 6 to 11 added in this section show how playing the game changed the way the group of 44 participants responded to the questionnaire.

Details about question 1 (*“Does using greywater reuse in households lead to a better water quality in the river downstream than using rainwater harvesting?”):* Initially, participants were split roughly 50/50 on deciding which technology between greywater reuse or rainwater harvesting would be best to minimise the pollution in the river downstream. After playing the game, **Figure 6** shows a 12% increase in the number of players answering the correct answer and realizing that installing rainwater harvesting in households significantly lowers the pollution index in the river downstream (the model behind the game captures the fact that rainwater harvesting tanks act as micro reservoirs that contain some of the rainfall and therefore prevent some of the runoff water to completely overwhelm the treatment capacity of wastewater treatment plants).

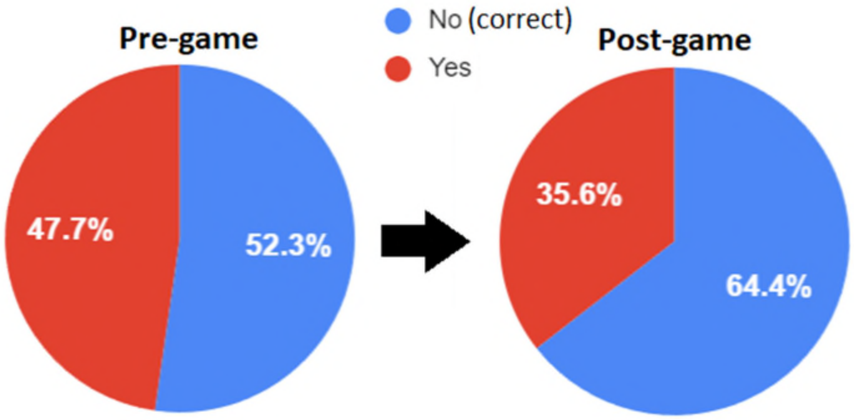


Figure 6. Answered to the question "Does using greywater reuse in households lead to a better water quality in the river downstream than using rainwater harvesting?" before and after playing the game.

A similar analysis for the answers to question 2 was not possible, because the formulation of the question was changed in between sessions following user feedback: participants reported that being asked to tick a box to confirm a negative statement ("Tick the box if you think this is INCORRECT" - that A is better than B) induced confusion. In contrast, in a live setting, most players were able to answer correctly when asked if the statement was CORRECT.

In question 3: (*"What is the relative importance of the wastewater treatment energy footprint compared to households water related devices?")*, more than half the players initially assumed wrongly that wastewater treatment and households would share the energy footprint in a fairly balanced 4:6 ratio. Post-game answers show a 37% increase towards the correct response (as shown in **Figure 7**) - that wastewater treatment only represents a tiny portion (2%) of the energy footprint, and that most of the energy savings could be done at the level of households.

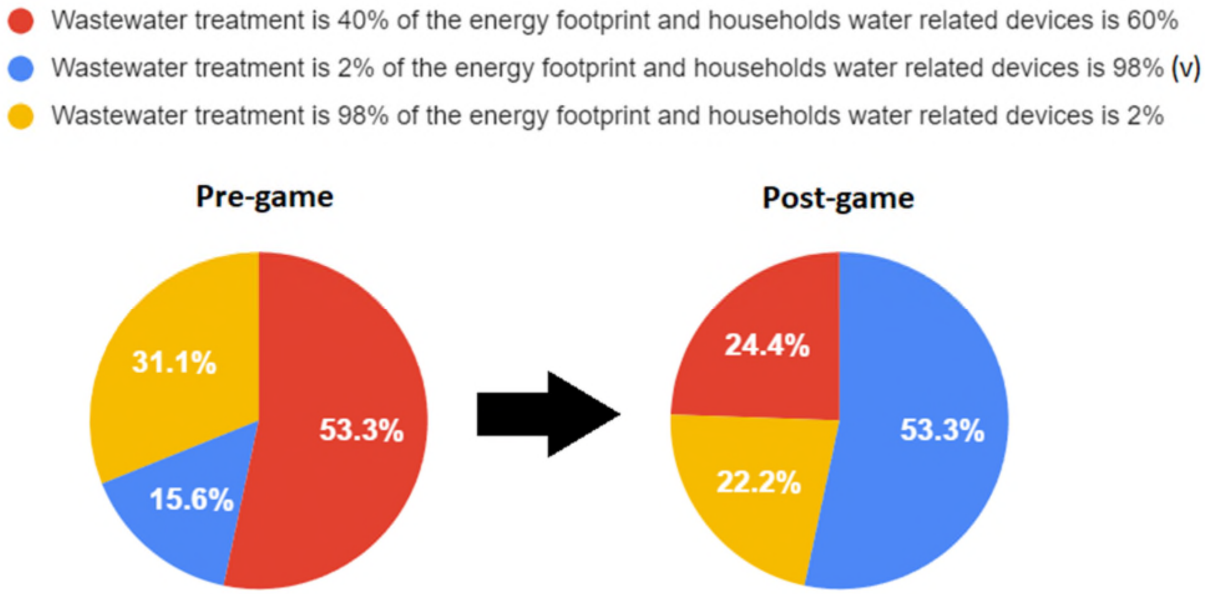


Figure 7. Answers to the question "What is the relative importance of the wastewater treatment energy footprint compared to households water related devices?" before and after playing the game.

Answering question 4 (*"We assume a reservoir is organized as a control system with a fairly high "baseline" discharge rate to the river and a lower "stressed" discharge rate that is applied when the reservoir is less than half full. Would maximising the "baseline" discharge rate to the river guarantee a greater environmental flow in the river?"*) correctly, requires either the participants to be familiar with control systems, or to have experimented with both the "baseline" and the "stressed" discharge rate of the reservoir enough to know that min-maxing these two parameters would not necessarily lead to the optimum solution. **Figure 8** shows that playing the game allowed 15% more participants to choose the correct answer.

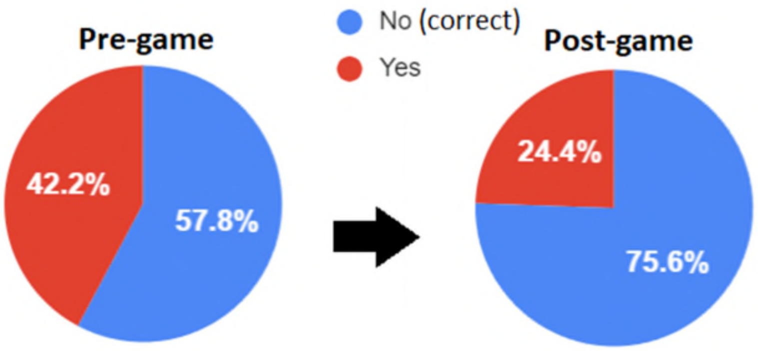


Figure 8. Answers to question 4 before and after playing the game.

Question 5 *("What would happen to the overall energy footprint and water quality in the river if you were to connect 20% of households of your town to decentralized wastewater treatment plants?")* is relatively difficult to answer from prior knowledge because it requires understanding how connecting households to a secondary treatment plant can impact water quality and energy use in opposite directions in the virtual catchment. Post-game answers show (see **Figure 9**) a 28% increase towards the correct response: players understood that connecting households to a nearby secondary wastewater treatment plant would consume less energy because of the reduced distance and associated pumping requirements. The game also displayed to the players an increase in the water quality downstream, because the game indicators show that discharges of untreated water are "shared" between the midstream and the downstream point of the river.

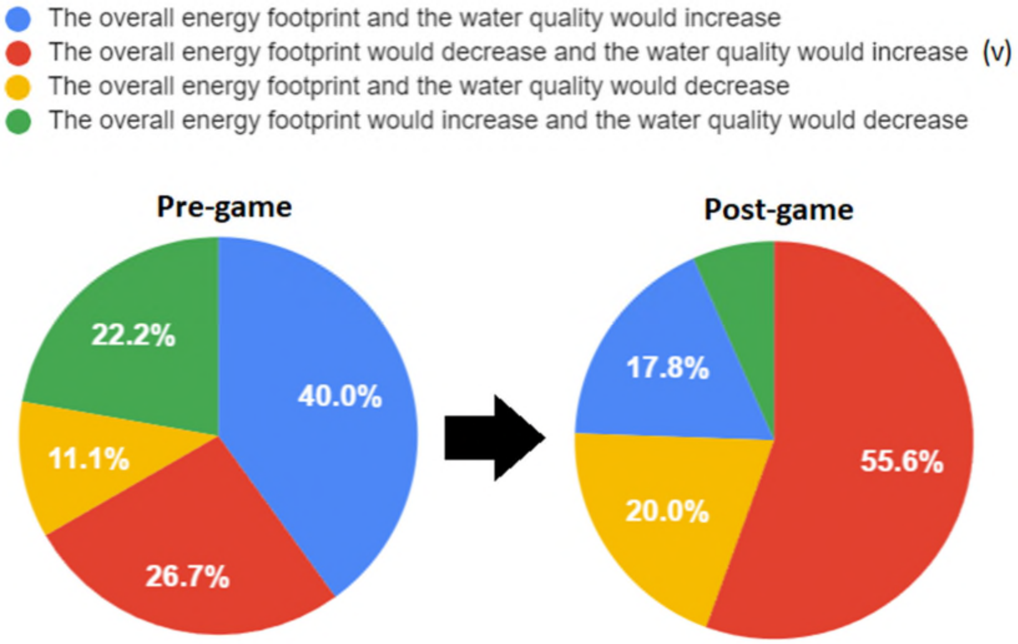


Figure 9. Answers to the question "What would happen to the overall energy footprint and water quality in the river if you were to connect 20% of households of your town to decentralized wastewater treatment plants?" before and after playing the game.

In question 6 (*"What would be the most important effect of installing a sustainable drainage system?"*), playing the serious game increased the perception of the role of Sustainable Drainage Systems as a way to reduce pollution downstream (**Figure 10** shows a 13% increase towards the correct answer).

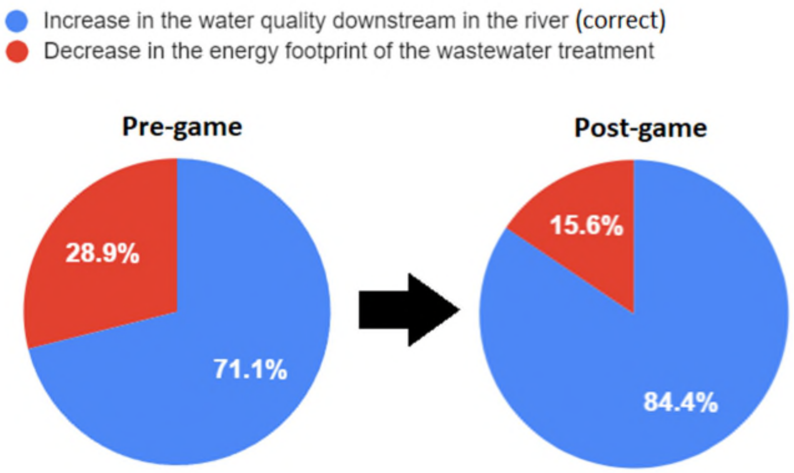


Figure 10. Answers to the question "What would be the most important effect of installing a sustainable drainage system?" before and after playing the game.

Finally, the answers to question 7 ("*which action would have the potential to save the most exergy and associated carbon footprint from domestic and industrial wastewater? Recycling nutrients from wastewater, or recycling traces of metal from wastewater?*"), show how the players, by playing the game, were influenced to revise their initial assumption about nutrients reuse having a greater potential to save energy and carbon emissions than metal reuse. (**Figure 11** shows a 51% increase towards the correct answer: recycling metals from wastewater**).**

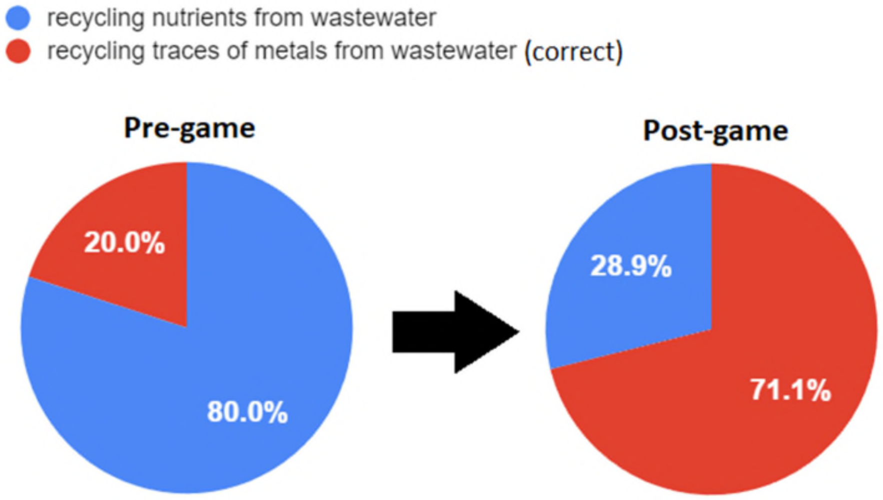


Figure 11. Answers to the question "Which action would have the potential to save the most exergy and associated carbon footprint from domestic and industrial wastewater?" before and after playing the game.

Playing the game led to an average improvement of 26% in the number of correct answers (where some of the given questions required understanding fairly technical concepts linked to the urban water cycle as detailed **in section 2.2**).

As a debate facilitation tool, the NEXTGEN serious game was used to support and illustrate points made by experts during a debate involving a panel of experts discussing at a “Net Zero roundtable” webinar organized by the Water Industry Process Automation & Control in November (2021). Some quotes illustrating some of the points made in the roundtable are visible in **appendix 10**. Firstly, potential energy savings for wastewater treatment plants were put into perspective compared to the households energy footprint (where the former represent about 2% of the water related energy footprint, while the latter represents around 98% of it), showing where the most savings could be achieved (see video available online at Water Industry Process Automation & Control, 2021; at minute 28). Secondly, the potential benefit for recycling metals going into the inlet of the wastewater treatment plant for a town of 300,000 inhabitants was emphasized because of the benefits in terms of exergy. Due to the fact that some metals have a relatively high and always increasing thermodynamic rarity, with the passing of time, they can take a substantial and greater amount of energy to mine further into the earth crust, refine, and transport. The exergy saved by recycling them when expressed in terms of carbon emission can be considerable. When expressed in equivalent Carbon sequestered quantified by the numbers of hectares of temperate forests planted yearly (same video at minute 31), interesting conclusions emerge regarding the overall potential of metal recovery technologies for the reduction of carbon emissions in the future.

Finally, the NEXTGEN Serious Game was used inside the Aquatech Innovation Forum in Amsterdam (November 2021) to create the world's first e-sport tournament event adapted to a professional water industry conference. Water experts from diverse backgrounds were first exposed to a generic demonstration of the virtual catchment and were then able to compete while contributing their own solutions to given problems of Circular Economy for water using the game interface, leading to one participant being elected as the winner at the end of the event. During the event, several companies expressed an interest in using the Serious Game to showcase their newest products (e.g. a novel type of greywater reuse filter for example) in a virtual catchment. This underlines the potential for a novel form of Serious Game based engagement akin to interactive marketing.

The game has been announced on social media and is now available online to play for anybody. Potential further use is presently being discussed as a mean to engage and inform policy makers for a recognized European member-based multistakeholder platform that promotes water-related innovation for the European Commission.

5. Conclusion

By combining a five-step hybrid learning methodology with a state-of-the-art real-time simulation engine, an innovative and flexible design, the NEXTGEN Serious Game has been successful at teaching classrooms and engaging audiences. Participants who joined the supervised training sessions were on average 26% more likely to correctly answer technical questions despite the added complexity of the subject studied: Circular Economy in the context of the urban water cycle. As a debate facilitation tool, the game also proved to be a surprisingly effective and thought-provoking tool able to contribute to the discussion by bringing multi-disciplinary insights: the most notable one being the potential of metal mining wastewater to save exergy and carbon emissions. Finally, the serious game was used to organize the first e-sport competitive tournament between water professionals at an industry conference. The software architecture allowed rapid and reliable deployment to be done at the scale required for the estimated number of users and at a reasonable cost. This achievement could mark the start of a new series of hybrid events that could soon take place in the water industry: conferences where experts compete against each other to solve complex problems via Serious Games.

Even though it shows promise as a training tool in the context of a classroom, and as an event enabler, it remains to be seen if this kind of Serious Game can address the biggest challenge that Water operators face nowadays: engaging and sensitising the general public, businesses, and policy makers to the problems and reality of water in the context of climate change, growing resources scarcity, and environmental decline. Further work still needs to be done to extend the reach of such Serious Games to an even wider audience, for example by building a catalogue of Serious Games tailored to specific audiences, problems, and situations.

6. ACKNOWLEDGMENTS

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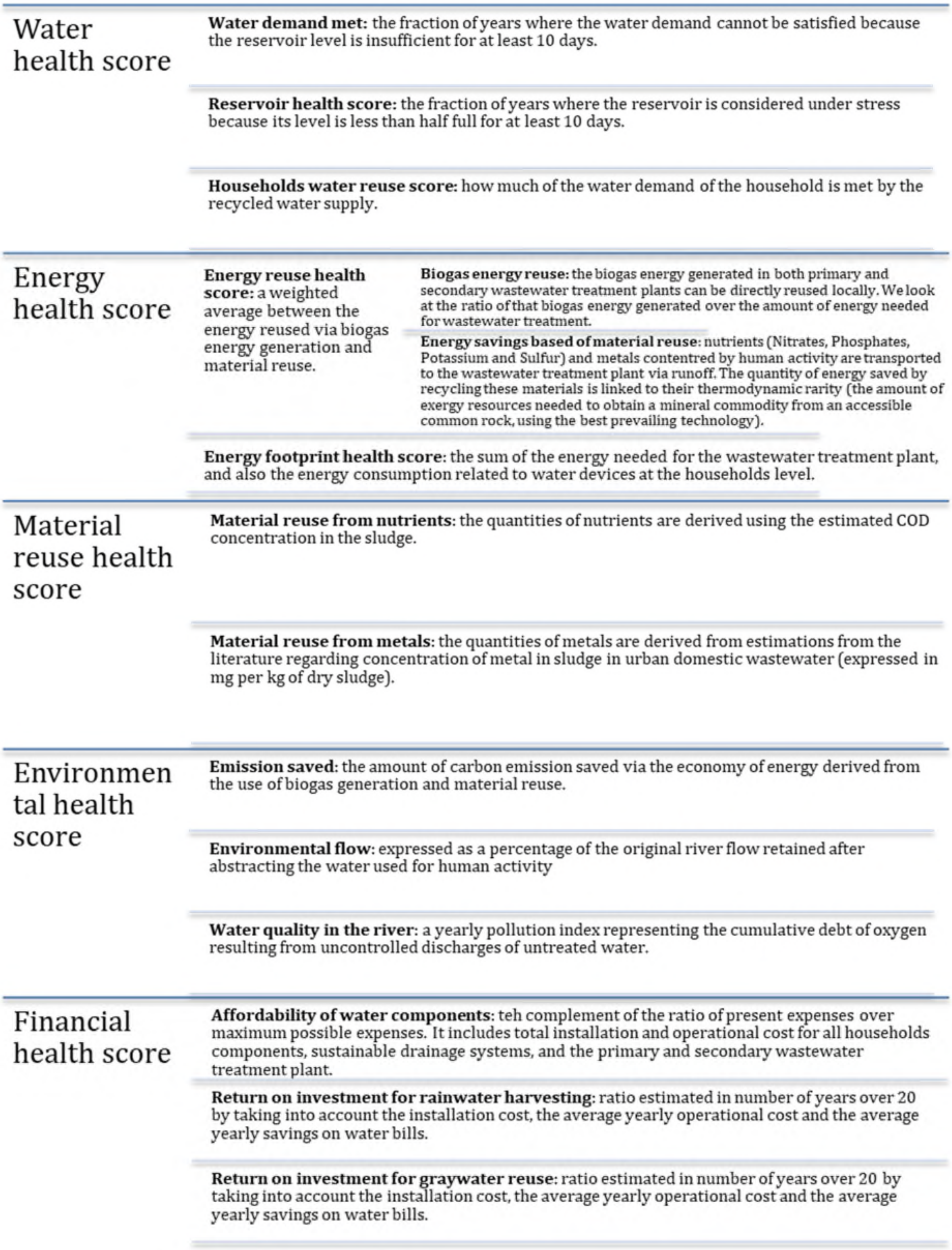
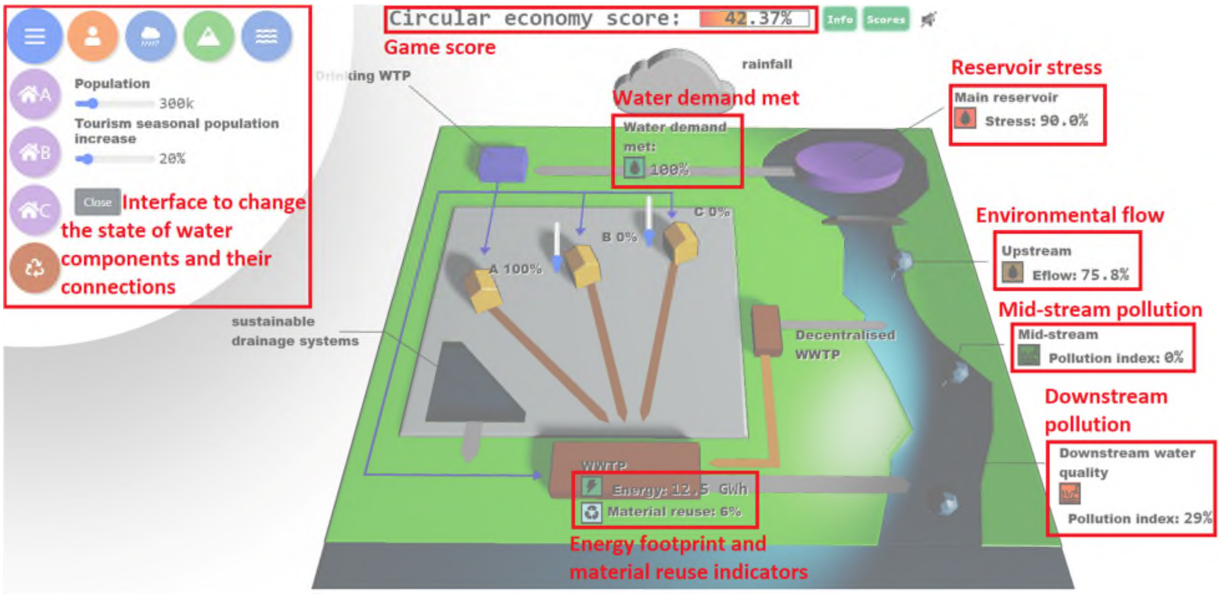
8. Appendices

A1 : Table detailing the different Key Performance Indicators that make the Circular Economy Score.

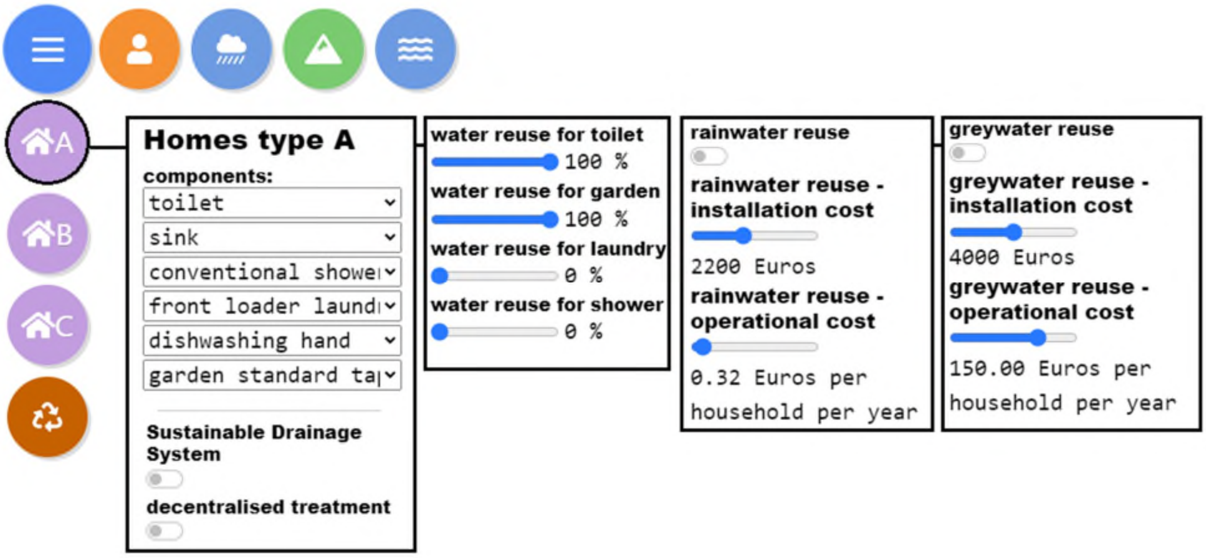


Water health score	**Water demand met:** the fraction of years where the water demand cannot be satisfied because the reservoir level is insufficient for at least 10 days.	
	Reservoir health score: the fraction of years where the reservoir is considered under stress because its level is less than half full for at least 10 days.	
	Households water reuse score: how much of the water demand of the household is met by the recycled water supply.	
Energy health score	**Energy reuse health score:** a weighted average between the energy reused via biogas energy generation and material reuse.	**Biogas energy reuse:** the biogas energy generated in both primary and secondary wastewater treatment plants can be directly reused locally. We look at the ratio of that biogas energy generated over the amount of energy needed for wastewater treatment.
		Energy savings based of material reuse: nutrients (Nitrates, Phosphates, Potassium and Sulfur) and metals contentred by human activity are transported to the wastewater treatment plant via runoff. The quantity of energy saved by recycling these materials is linked to their thermodynamic rarity (the amount of exergy resources needed to obtain a mineral commodity from an accessible common rock, using the best prevailing technology).
	Energy footprint health score: the sum of the energy needed for the wastewater treatment plant, and also the energy consumption related to water devices at the households level.	
Material reuse health score	**Material reuse from nutrients:** the quantities of nutrients are derived using the estimated COD concentration in the sludge.	
	Material reuse from metals: the quantities of metals are derived from estimations from the literature regarding concentration of metal in sludge in urban domestic wastewater (expressed in mg per kg of dry sludge).	
Environmental health score	**Emission saved:** the amount of carbon emission saved via the economy of energy derived from the use of biogas generation and material reuse.	
	Environmental flow: expressed as a percentage of the original river flow retained after abstracting the water used for human activity	
	Water quality in the river: a yearly pollution index representing the cumulative debt of oxygen resulting from uncontrolled discharges of untreated water.	
Financial health score	**Affordability of water components:** teh complement of the ratio of present expenses over maximum possible expenses. It includes total installation and operational cost for all households components, sustainable drainage systems, and the primary and secondary wastewater treatment plant.	
	Return on investment for rainwater harvesting: ratio estimated in number of years over 20 by taking into account the installation cost, the average yearly operational cost and the average yearly savings on water bills.	
	Return on investment for graywater reuse: ratio estimated in number of years over 20 by taking into account the installation cost, the average yearly operational cost and the average yearly savings on water bills.	

A2: Highlighting the serious game interface and essential indicators



A3: Part of the interface allowing to swap water technologies within households, and switch connections with sustainable drainages systems and primary or secondary wastewater treatment


Homes type A

components:

- toilet
- sink
- conventional showe
- front loader laund
- dishwashing hand
- garden standard ta

Sustainable Drainage System ○

decentralised treatment ○

water reuse for toilet 100 %

water reuse for garden 100 %

water reuse for laundry 0 %

water reuse for shower 0 %

rainwater reuse ○

rainwater reuse - installation cost 2200 Euros

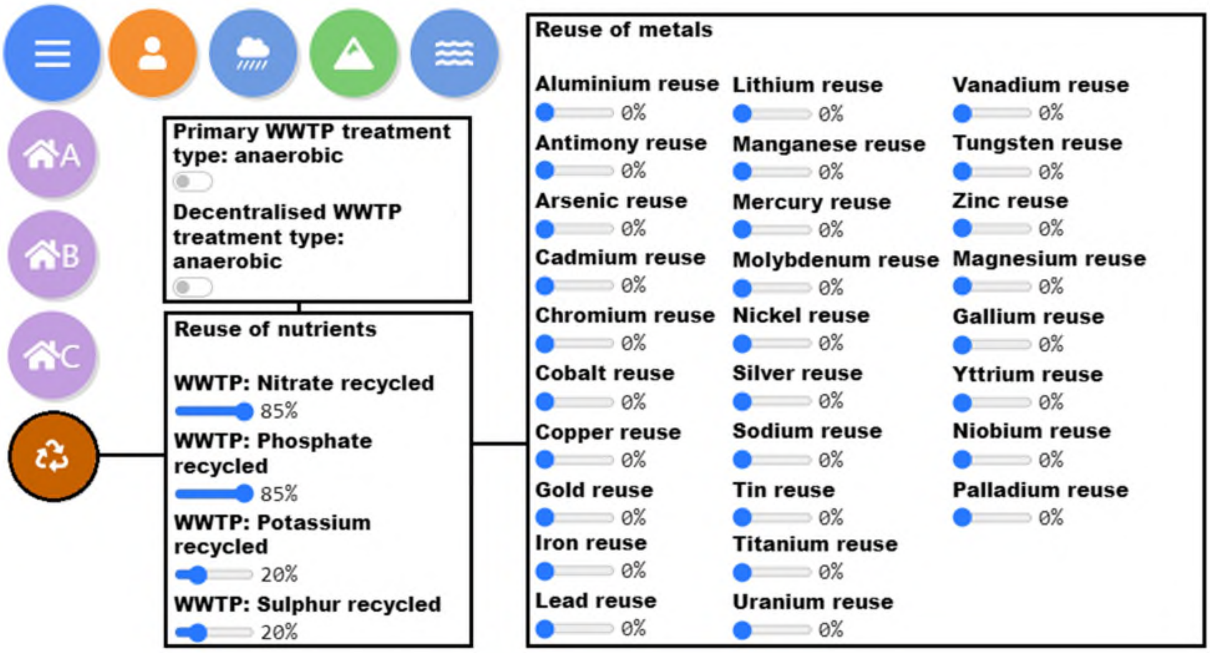
rainwater reuse - operational cost 0.32 Euros per household per year

greywater reuse ○

greywater reuse - installation cost 4000 Euros

greywater reuse - operational cost 150.00 Euros per household per year

A4: Part of the interface allowing to activate anaerobic wastewater treatment (biogas generation) and recycle nutrients and metals present in the sludge



Primary WWTP treatment type: anaerobic
○

Decentralised WWTP treatment type: anaerobic
○

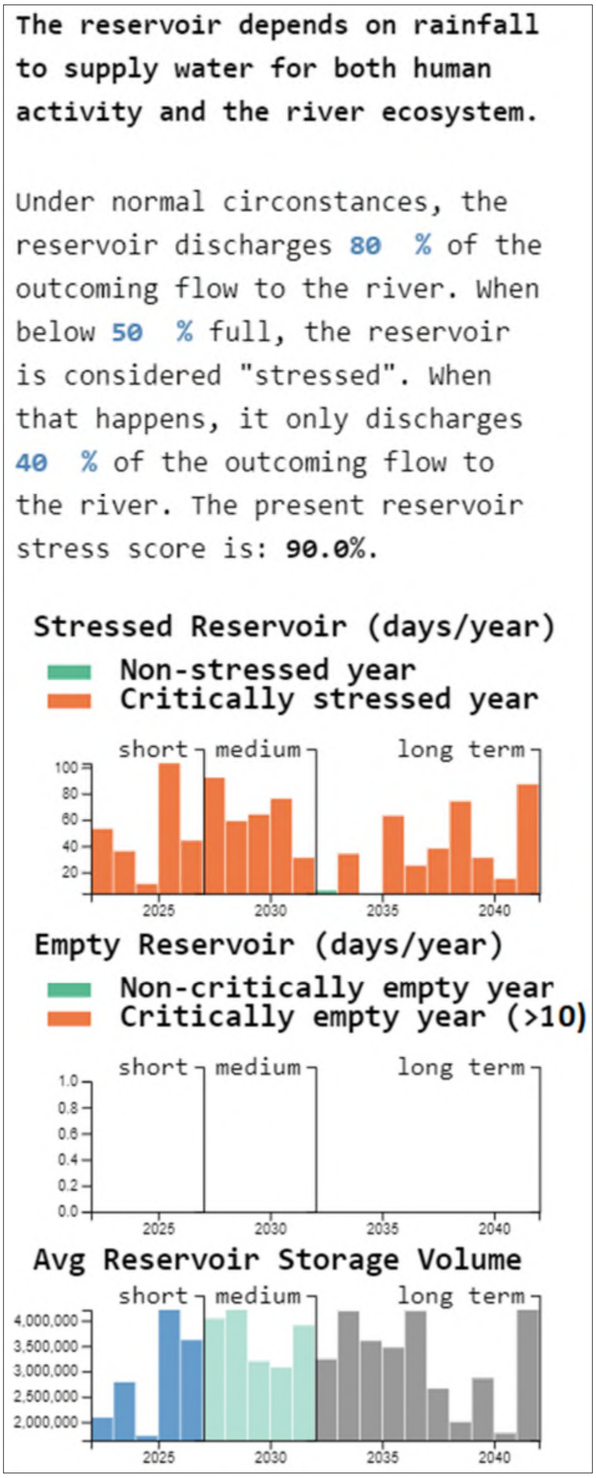
Reuse of nutrients

WWTP: Nitrate recycled 85%
WWTP: Phosphate recycled 85%
WWTP: Potassium recycled 20%
WWTP: Sulphur recycled 20%

Reuse of metals

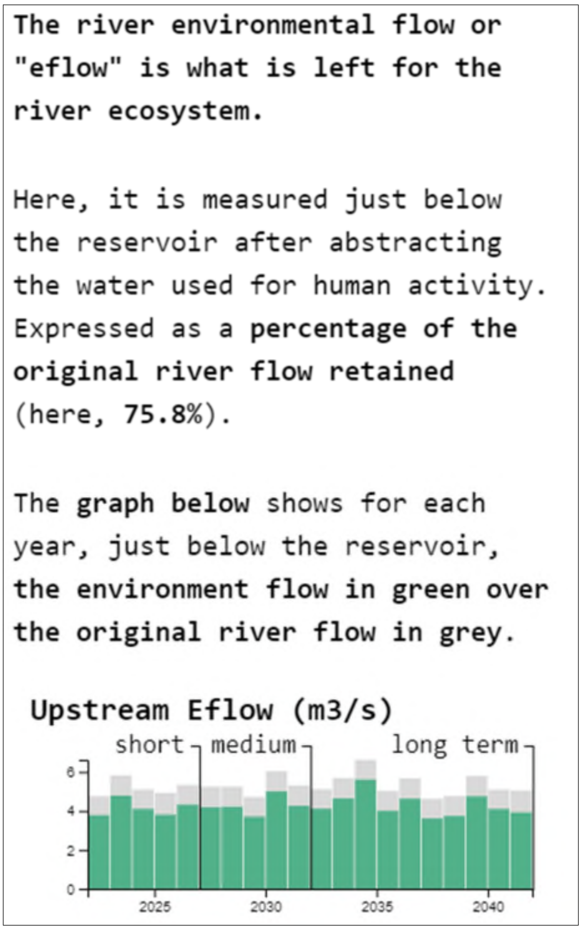
Aluminium reuse 0%
Antimony reuse 0%
Arsenic reuse 0%
Cadmium reuse 0%
Chromium reuse 0%
Cobalt reuse 0%
Copper reuse 0%
Gold reuse 0%
Iron reuse 0%
Lead reuse 0%
Lithium reuse 0%
Manganese reuse 0%
Mercury reuse 0%
Molybdenum reuse 0%
Nickel reuse 0%
Silver reuse 0%
Sodium reuse 0%
Tin reuse 0%
Titanium reuse 0%
Uranium reuse 0%
Vanadium reuse 0%
Tungsten reuse 0%
Zinc reuse 0%
Magnesium reuse 0%
Gallium reuse 0%
Yttrium reuse 0%
Niobium reuse 0%
Palladium reuse 0%

A5 : Screen capture of reservoir information (left), environmental flow information (top right), river midstream pollution information (lower right) that popup when a user click on the related icons.



The reservoir depends on rainfall to supply water for both human activity and the river ecosystem.

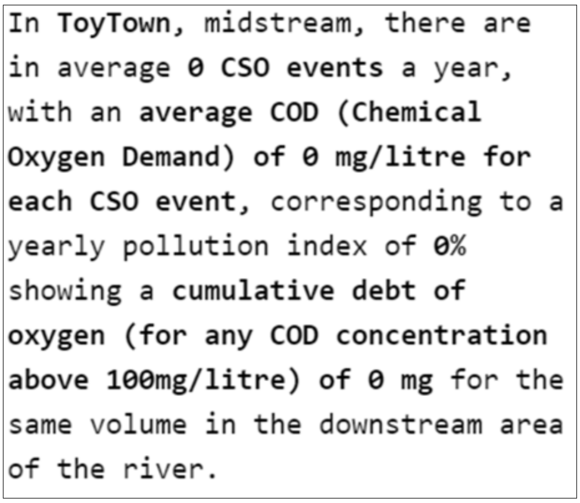
Under normal circonstances, the reservoir discharges **80** % of the outcoming flow to the river. When below **50** % full, the reservoir is considered "stressed". When that happens, it only discharges **40** % of the outcoming flow to the river. The present reservoir stress score is: **90.0%**.



The river environmental flow or "eflow" is what is left for the river ecosystem.

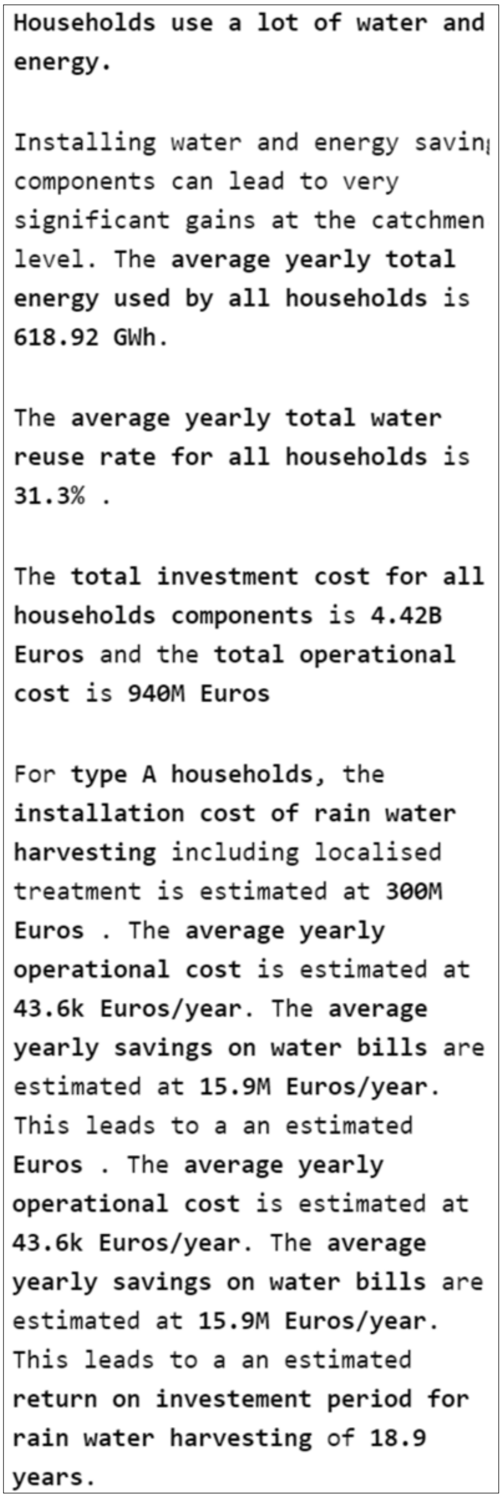
Here, it is measured just below the reservoir after abstracting the water used for human activity. Expressed as a **percentage of the original river flow retained** (here, **75.8%**).

The **graph below** shows for each year, just below the reservoir, **the environment flow in green over the original river flow in grey.**



In **ToyTown**, midstream, there are in average **0 CSO events** a year, with an **average COD (Chemical Oxygen Demand) of 0 mg/litre for each CSO event**, corresponding to a yearly pollution index of **0%** showing a **cumulative debt of oxygen (for any COD concentration above 100mg/litre) of 0 mg** for the same volume in the downstream area of the river.

A6: Screen capture of household's water reuse information



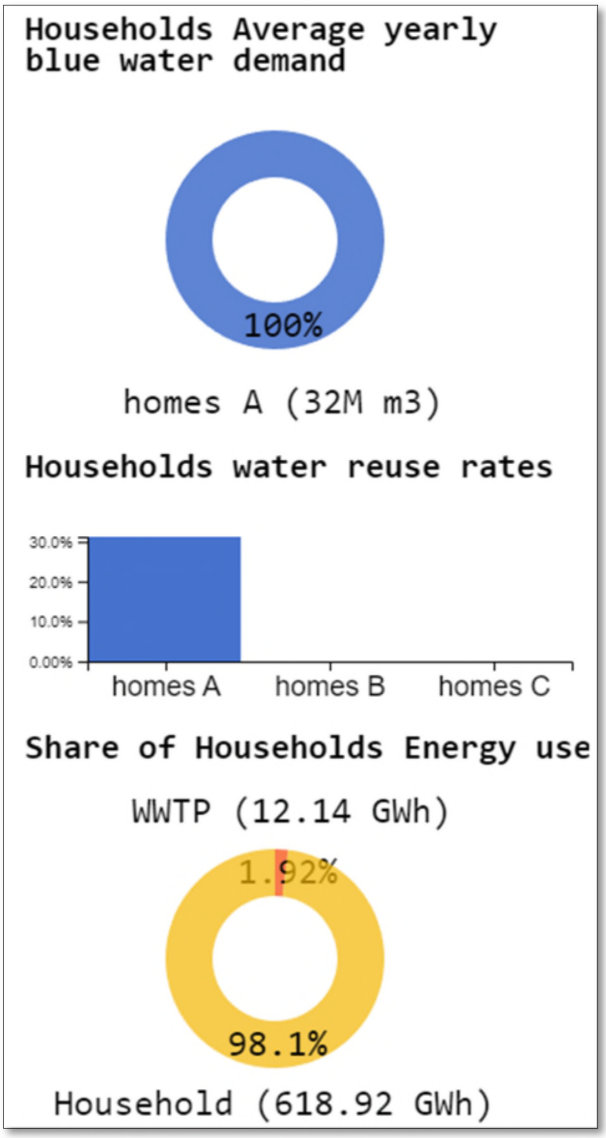
Households use a lot of water and energy.

Installing water and energy savin components can lead to very significant gains at the catchmen level. The average yearly total energy used by all households is 618.92 GWh.

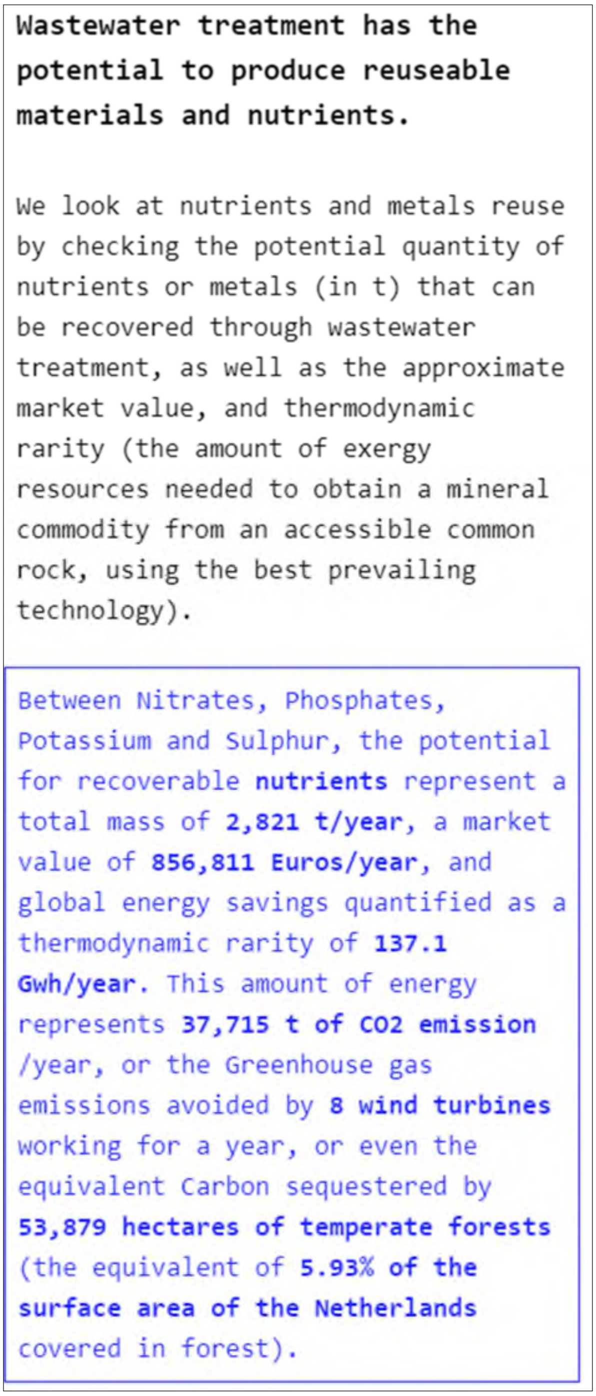
The average yearly total water reuse rate for all households is 31.3% .

The total investment cost for all households components is 4.42B Euros and the total operational cost is 940M Euros

For type A households, the installation cost of rain water harvesting including localised treatment is estimated at 300M Euros . The average yearly operational cost is estimated at 43.6k Euros/year. The average yearly savings on water bills are estimated at 15.9M Euros/year. This leads to a an estimated Euros . The average yearly operational cost is estimated at 43.6k Euros/year. The average yearly savings on water bills are estimated at 15.9M Euros/year. This leads to a an estimated return on investement period for rain water harvesting of 18.9 years.



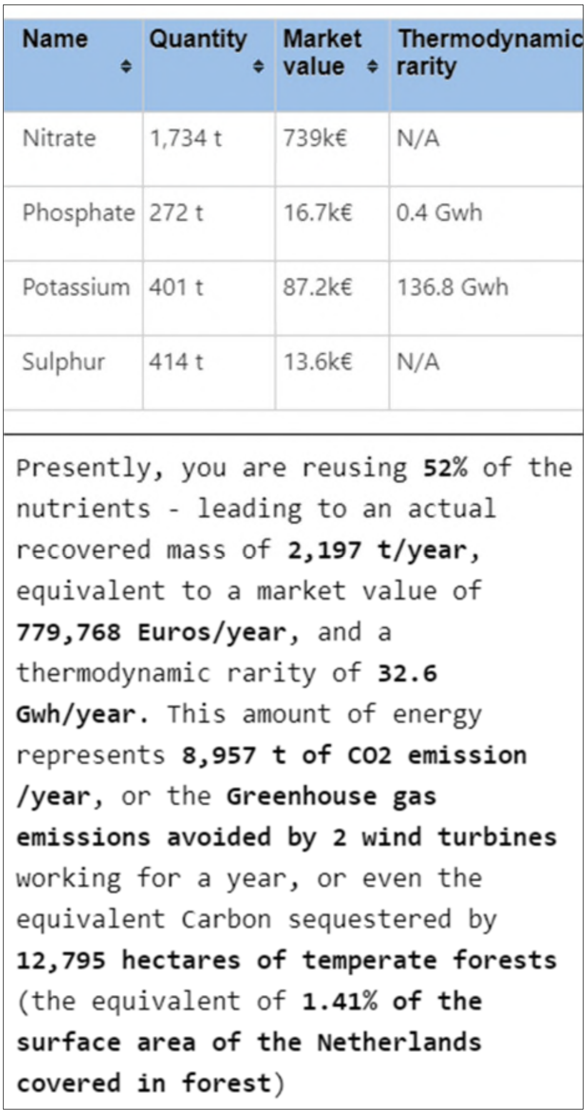
A7: Screen capture of material reuse information related to nutrients



Wastewater treatment has the potential to produce reuseable materials and nutrients.

We look at nutrients and metals reuse by checking the potential quantity of nutrients or metals (in t) that can be recovered through wastewater treatment, as well as the approximate market value, and thermodynamic rarity (the amount of exergy resources needed to obtain a mineral commodity from an accessible common rock, using the best prevailing technology).

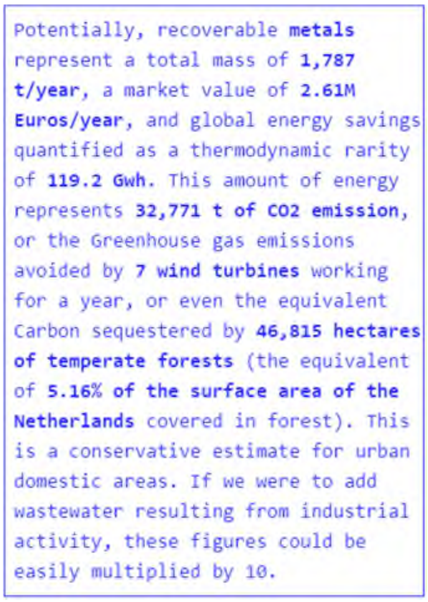
Between Nitrates, Phosphates, Potassium and Sulphur, the potential for recoverable **nutrients** represent a total mass of **2,821 t/year**, a market value of **856,811 Euros/year**, and global energy savings quantified as a thermodynamic rarity of **137.1 Gwh/year**. This amount of energy represents **37,715 t of CO2 emission** /year, or the Greenhouse gas emissions avoided by **8 wind turbines** working for a year, or even the equivalent Carbon sequestered by **53,879 hectares of temperate forests** (the equivalent of **5.93% of the surface area of the Netherlands** covered in forest).



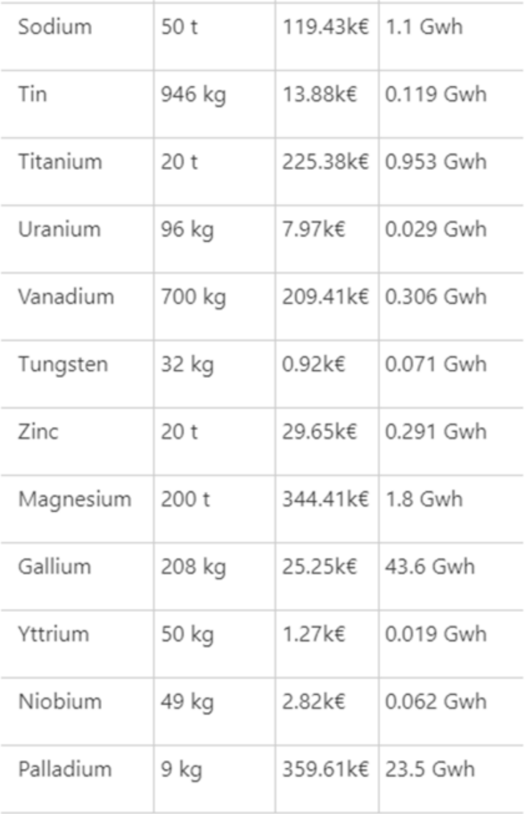
Name ⬍	Quantity ⬍	Market value ⬍	Thermodynamic rarity
Nitrate	1,734 t	739k€	N/A
Phosphate	272 t	16.7k€	0.4 Gwh
Potassium	401 t	87.2k€	136.8 Gwh
Sulphur	414 t	13.6k€	N/A

Presently, you are reusing **52%** of the nutrients - leading to an actual recovered mass of **2,197 t/year**, equivalent to a market value of **779,768 Euros/year**, and a thermodynamic rarity of **32.6 Gwh/year**. This amount of energy represents **8,957 t of CO2 emission /year**, or the **Greenhouse gas emissions avoided by 2 wind turbines** working for a year, or even the equivalent Carbon sequestered by **12,795 hectares of temperate forests** (the equivalent of **1.41% of the surface area of the Netherlands covered in forest**)

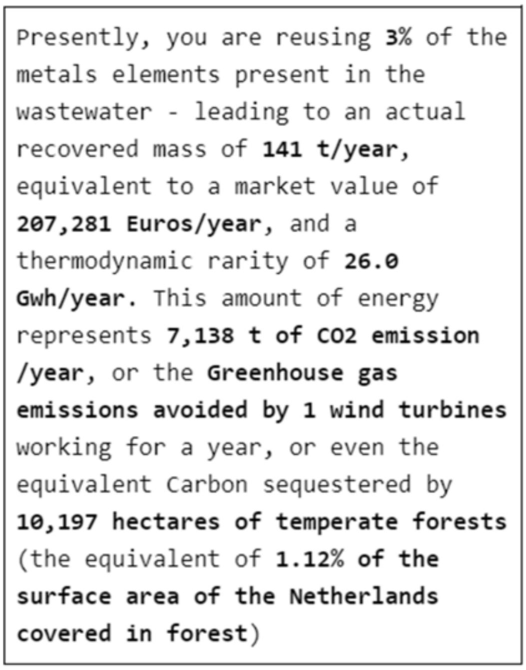
A8 : Screen capture of material reuse information related to metals



Potentially, recoverable **metals** represent a total mass of **1,787 t/year**, a market value of **2.61M Euros/year**, and global energy savings quantified as a thermodynamic rarity of **119.2 Gwh**. This amount of energy represents **32,771 t of CO2 emission**, or the Greenhouse gas emissions avoided by **7 wind turbines** working for a year, or even the equivalent Carbon sequestered by **46,815 hectares of temperate forests** (the equivalent of **5.16% of the surface area of the Netherlands** covered in forest). This is a conservative estimate for urban domestic areas. If we were to add wastewater resulting from industrial activity, these figures could be easily multiplied by 10.

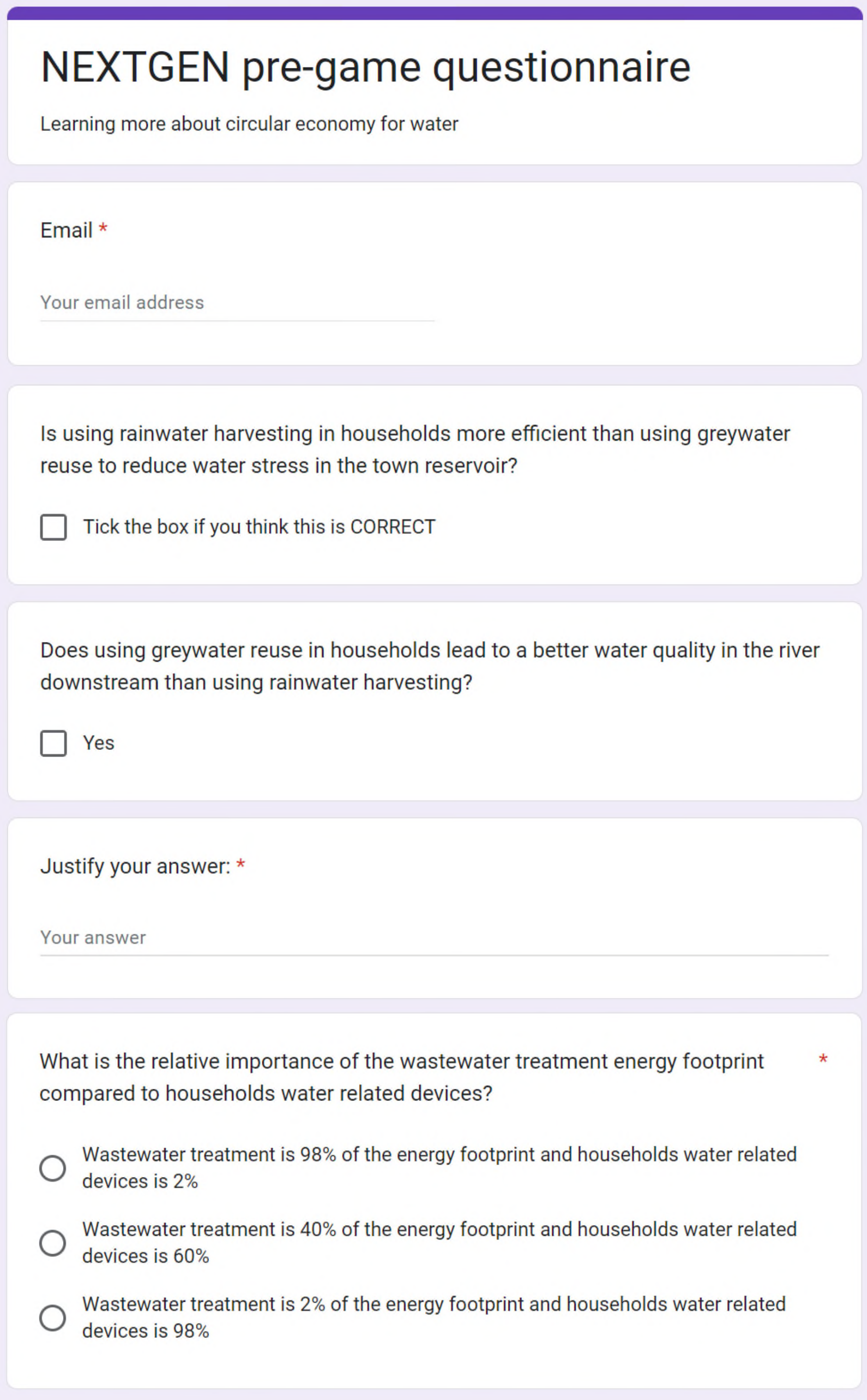


Name	Quantity	Market value	Thermodynan rarity
Aluminium	100 t	207.28k€	26.0 Gwh
Antimony	32 kg	0.15k€	0.004 Gwh
Arsenic	258 kg	0.24k€	0.031 Gwh
Cadmium	92 kg	0.21k€	0.164 Gwh
Chromium	1 t	11.29k€	0.017 Gwh
Cobalt	89 kg	2.38k€	0.271 Gwh
Copper	10 t	54.26k€	0.492 Gwh
Gold	8 kg	418.06k€	6.2 Gwh
Iron	1322 t	459.73k€	11.7 Gwh
Lead	618 kg	0.93k€	0.007 Gwh
Lithium	454 kg	30.70k€	0.123 Gwh
Manganese	40 t	57.82k€	0.788 Gwh
Mercury	35 kg	0.88k€	0.283 Gwh
Molybdenum	199 kg	6.54k€	0.058 Gwh
Nickel	704 kg	8.01k€	0.171 Gwh
Silver	424 kg	8.92k€	1.1 Gwh
Sodium	50 t	119.43k€	1.1 Gwh
Tin	946 kg	13.88k€	0.119 Gwh
Titanium	20 t	225.38k€	0.953 Gwh
Uranium	96 kg	7.97k€	0.029 Gwh
Vanadium	700 kg	209.41k€	0.306 Gwh
Tungsten	32 kg	0.92k€	0.071 Gwh
Zinc	20 t	29.65k€	0.291 Gwh
Magnesium	200 t	344.41k€	1.8 Gwh
Gallium	208 kg	25.25k€	43.6 Gwh
Yttrium	50 kg	1.27k€	0.019 Gwh
Niobium	49 kg	2.82k€	0.062 Gwh
Palladium	9 kg	359.61k€	23.5 Gwh



Presently, you are reusing **3%** of the metals elements present in the wastewater - leading to an actual recovered mass of **141 t/year**, equivalent to a market value of **207,281 Euros/year**, and a thermodynamic rarity of **26.0 Gwh/year**. This amount of energy represents **7,138 t of CO2 emission /year**, or the **Greenhouse gas emissions avoided by 1 wind turbines** working for a year, or even the equivalent Carbon sequestered by **10,197 hectares of temperate forests** (the equivalent of **1.12% of the surface area of the Netherlands covered in forest**)

A9 : Screen capture of online pre-game (also identical to post-game) questionnaire



NEXTGEN pre-game questionnaire

Learning more about circular economy for water

Email *

Your email address

Is using rainwater harvesting in households more efficient than using greywater reuse to reduce water stress in the town reservoir?

☐ Tick the box if you think this is CORRECT

Does using greywater reuse in households lead to a better water quality in the river downstream than using rainwater harvesting?

☐ Yes

Justify your answer: *

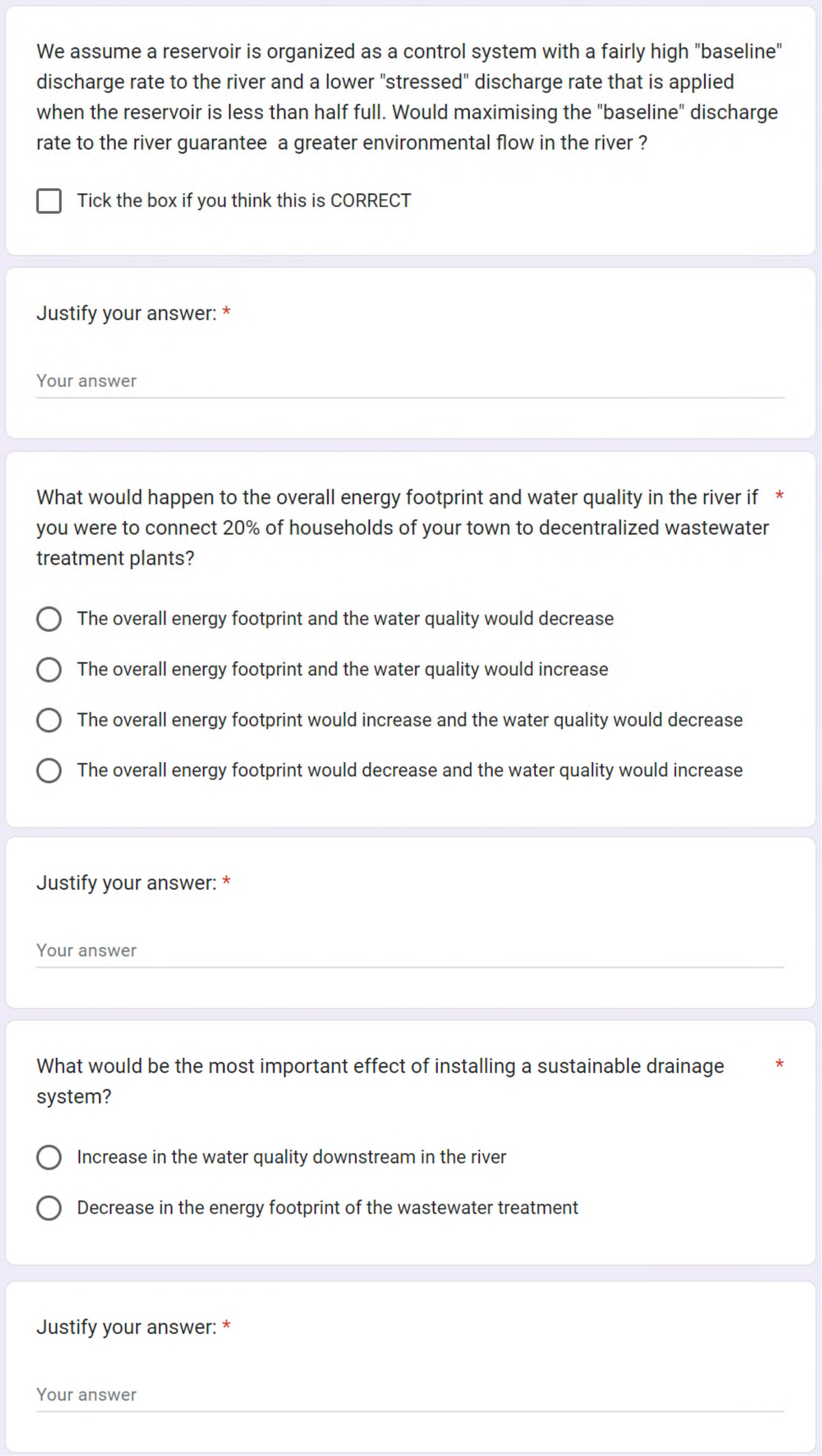
Your answer

What is the relative importance of the wastewater treatment energy footprint compared to households water related devices? *

○ Wastewater treatment is 98% of the energy footprint and households water related devices is 2%

○ Wastewater treatment is 40% of the energy footprint and households water related devices is 60%

○ Wastewater treatment is 2% of the energy footprint and households water related devices is 98%



We assume a reservoir is organized as a control system with a fairly high "baseline" discharge rate to the river and a lower "stressed" discharge rate that is applied when the reservoir is less than half full. Would maximising the "baseline" discharge rate to the river guarantee a greater environmental flow in the river ?

☐ Tick the box if you think this is CORRECT

Justify your answer: *

Your answer

What would happen to the overall energy footprint and water quality in the river if you were to connect 20% of households of your town to decentralized wastewater treatment plants? *

○ The overall energy footprint and the water quality would decrease

○ The overall energy footprint and the water quality would increase

○ The overall energy footprint would increase and the water quality would decrease

○ The overall energy footprint would decrease and the water quality would increase

Justify your answer: *

Your answer

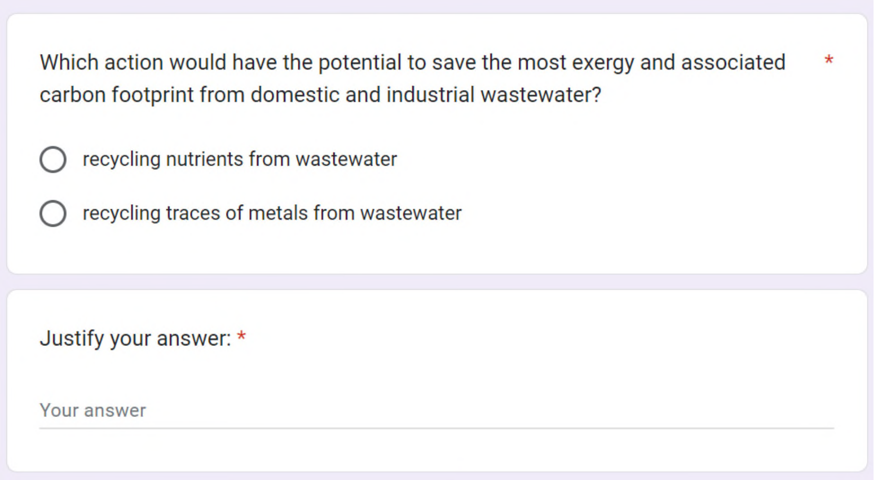
What would be the most important effect of installing a sustainable drainage system? *

○ Increase in the water quality downstream in the river

○ Decrease in the energy footprint of the wastewater treatment

Justify your answer: *

Your answer



Which action would have the potential to save the most exergy and associated carbon footprint from domestic and industrial wastewater? *

○ recycling nutrients from wastewater

○ recycling traces of metals from wastewater

Justify your answer: *

Your answer

A10: Transcriptions/quotes from the Water Industry Process Automation & Control roundtable experts

Participant 1: *"...but I think it's also having that information in a digestible format...Yeah, understanding those links, but understanding in a way that we can communicate to the policy makers, can communicate to the decision makers, can communicate to whoever we need to communicate to..."*

Participant 2: *"I think it's really worth picking up on what (the game designer) has done there because it's so important. What he is doing by using exergy in the analysis is he is showing how energy and carbon are related across a whole area of activity... From cradle to grave to a degree… Part of the issue here, is that current economics simply doesn't include that. The doctrine of externalities that's used in conventional economics ignores how some of these costs accumulate between one area of the economy to the other. So, at the moment [...] our economic policy making is blind to the type of thing that the game has just showed us […]. So, again, with regards to the gaming, the more information we can provide to point out where we're not understanding things at the moment, the more powerful an argument we've got to get us to start doing the right things."*

Participant 3: "*I think it's extremely interesting... this serious game by media, and what I really appreciate (which is sort of a hard moment for me) also is that we are very occupied in Denmark in my utility like... we want to be, our utility has to be clean. So, we have to, sort of, have zero carbon within our own scope. So, it would never have occurred to us to look into rare metals because it simply doesn't make a bleep in in our system! And looking at these fog showers that I never heard about...I really think to expand the scope. [...] even for us, it's very difficult just to find out our own backyard, but to look across it, I think that's very interesting. And I think, it could be very helpful for many utilities to play this game to sort of play around with what we can do. And, I'm, yeah, I'm very impressed!"*