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Circular economy in the water and wastewater sector: Tariff impact and financial performance of SMARTechs

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ABSTRACT

This paper proposes a financial evaluation of the investment in SMARTechs in wastewater companies. SMARTechs are innovative technologies that enable companies to work toward the circular economy approach, thanks to allowing the development of by-products from wastewater. A simulation of the financial impact of the SMARTech introduction was conducted based on the Italian tariff system. It is performed assuming two different scenarios. These relate to a market's presence (or absence) for the by-products resulting from the application of SMARTechs. The results show that investing in these technologies provides both financial and environmental benefits.

1. Introduction

Water is vital for human health and survival and plays a crucial role in sustainable ecosystem services, political stability, and socio-economic development, given the many types of industries that depend on it (Jokar et al., 2021; Mauchauffee et al., 2012). According to Abu-Ghunmi et al. (2016) and Nika et al. (2020), in the environment, water undergoes a cycle sustained by natural processes, including precipitation, infiltration, evapotranspiration, and condensation. However, as Voulvoulis (2018) pointed out, water resources are unevenly distributed in space and time, and are increasingly under pressure due to population growth and the growing global economy. In recent years, this increasing pressure has reached a critical level, regarding reduced water availability and compromised water quality, such that water has become unfit for further use by humans and ecosystems (Şahin and Manioğlu, 2019). To counter such scarcity, the principle of the circular economy (CE) may be implemented (International Water Association [IWA], 2016; Voulvoulis, 2018). The linear economy is based on the "take, make, use, and dispose" concept, wherein waste represents the last stage of the product life cycle (Neczaj and Grosser, 2018). In a CE, products, and materials (including raw materials) should remain in the economy for as long as possible, and waste should be treated as secondary raw materials that can be recycled to process and reuse (Ghisellini et al., 2016).

Concerning the European economy, in 2014, under the program "Toward a Circular Economy: A Zero Waste Program for Europe," the European Commission provided its first definition of a CE as a "system which keeps the added value in products for as long as possible and eliminates waste" (Commission of European Communities, 2014, p.2). In 2015, in a second communication, "Closing the Loop – An EU Action Plan for the Circular Economy," an extended definition was provided: a "circular economy is a system where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste is minimized" (Commission of European Communities, 2015). Accordingly, two essential aspects play a significant role: a more rational use of resources and waste management. In this context, a more rational use of water resources and more sustainable wastewater practices are considered a way toward a CE in the water and wastewater sector (Smol et al., 2020).

The key legal acts that form the basis of the EU's commitment to improve the state of Europe's waters are the Water Framework Directive (WFD; Directive, 2000/60/EC), the Urban Wastewater Treatment Directive (Council Directive 91/271/EEC), and the Drinking Water Directive (Council Directive 2184/20/EC). In this regard, the concept of the CE adopted by the European Commission could enhance the actions recommended in the wastewater directives to protect water resources and the environment in Europe. However, this would require a new

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approach to water and wastewater management, as well as the development and implementation of innovation in technologies, organizations, policies, society, and financial structures (Smol et al., 2017). In this context, the Horizon 2020 (H2020) innovation action SMART-Plant was proposed in 2015 and funded in 2016 (https://www.smart-plant.eu). This project involved universities and the private sector to provide innovative solutions for resource recovery and reuse in the urban water sector. Through nine innovative technologies, it validated eco-innovative solutions that upgraded wastewater treatment plants (WWTPs) into water resource recovery plants. It paved the way to realizing a CE by demonstrating sustainable cross-sector value chains (Foglia et al., 2021). The overall objective of SMART-Plant was to support the water sector to improve and ensure environmental protection, become more adaptive, and respond to current environmental and social challenges by introducing innovative technological solutions and moving toward resource recovery approaches to wastewater management. This can be achieved by applying low carbon footprint technologies to provide high-quality treated water and recover materials that would otherwise be lost (such as cellulose, stabilized biofertilizer, and struvite), to demonstrate the feasibility of the entire recycling chain. The project contributed to the change in the current water management perspectives toward resource recovery. Overall, the goal of SMART-Plant was to validate and provide the market with a portfolio of SMARTechs that, individually or in combination, could innovate and upgrade existing WWTPs and give the added value of instituting a paradigm shift toward efficient wastewater-based biorefineries (Fatone et al., 2017).

This article seeks to respond to calls for more empirical studies on applying the CE from managerial (e.g., De Angelis, 2020) and water and wastewater sector (Mbavarira and Grimm, 2021) literatures. Some authors have argued that more emphasis should be placed on the organizational, social, and regulatory evolution necessary to successfully implement new technologies (Smith et al., 2018; Smol et al., 2020). In fact, although many studies highlight the environmental and social benefits of the introduction of new technologies in the water and wastewater sector (e.g., Foglia et al., 2021), to the best of the authors' knowledge, few have explored at the organizational and regulatory levels the long-term financial sustainability of investments in these technologies in Integrated Water System (IWS) companies (see Abu-Ghunmi et al., 2016). To fill this gap, this study analyzes financial results based on the simulation of the Italian tariff related to the inclusion (or not) of SMARTechs in existing WWTPs in several European countries that are partners of the SMART-Plant project. The Italian tariff scheme was selected to employ a homogeneous method of calculating revenues and costs from the introduction of this technology. Indeed, based on recent regulatory developments designed to include essential incentives for IWS companies implementing these technologies, the Italian tariff calculation procedure is considered by WAREG (2019), European Federation of National Associations of Water Services (2018), and ARERA (2021) to be one of the most advanced in introducing CE principles in pricing. The analysis was performed under two scenarios: first, the presence of a market for selling products derived from this technology, and second, the absence of such a market. This evaluation arises from the need to investigate whether, beyond tariff regulation, there might be additional aspects that can foster the deployment of these technologies, such as the presence of a market for by-products.

The article is organized as follows. We first conduct a literature review to introduce CE principles in the water and wastewater sector. We then perform an analysis of the different European tariff systems in the context of the CE, with a focus on the evolution of the Italian system. Following that, we provide a brief description of each SMARTech, the characteristics of the Italian tariff calculation, and the two scenarios under which the simulation is conducted. We then present the results and discussion, which focus on the findings and implications of our analysis, and finally, the conclusions, which highlight the strengths and weaknesses of the study.

2. the circular economy and the water sector

The CE literature spans various topics and sectors, including (e.g., Lieder and Rashid, 2016), supply chain management (e.g., Hazen et al., 2020), and electronics (e.g., Choudhary et al., 2022); however, CE literature focusing on the water sector is relatively recent (Mbavarira and Grimm, 2021). In addition, the authors pointed out that the CE has an especially high potential for development in the water sector since it is considered the heart of the CE; that is, a facilitator of the transition from the linear model on a global level. Therefore, to foster the implementation of a CE in the water sector, Smol et al. (2020) proposed a framework to clarify the actions that need to be taken across the following six technological, organizational, and societal aspects:

1. reduction—reducing water usage, wastewater generation, and pollution.
2. reclamation (removal)—removing pollutants from water and wastewater with effective technologies.
3. reuse—reusing wastewater for non-potable use.
4. recycle—recycling water and recovering it for potable usage from wastewater.
5. recovery—recovering resources, such as extracting nutrients and generating energy from sludge.
6. rethink—rethinking how to use resources sustainably without producing waste and emissions.

Consistent with this framework, several empirical studies have been conducted (see Table 1, which summarizes possible actions to implement a CE in the water and wastewater sector). Hence, decentralized wastewater management, digitization, water reuse, and resource recovery could strengthen circularity in the water sector (Mbavarira and Grimm, 2021). More in detail, decentralized wastewater management is employed to treat and dispose small amounts of wastewater at or near the source (Capodaglio, 2017) and can meet needs for water use and reuse, with particular applicability to developing countries (Massoud et al., 2009). Ghafourian et al. (2022) proposed impact assessment indicators of a CE in a decentralized circular water system in Greece, pointing out the relevance of environmental and social aspects in the overall assessment. Furthermore, the transition to digital technologies is increasingly necessary to ensure CE development in the companies involved in the water service. This can be achieved by developing a digital strategy, embedding it in the company's business strategy, and ensuring it is well communicated and implemented (Grievson et al., 2022). Eggimann et al. (2017) examined new approaches to improve network efficiency – some of which are aligned with the CE paradigm; for example, pipe condition monitoring that can automatically detect leaks, thereby reducing water loss. However, several may be obstacles in implementing technologies for CE. In this regard, digital know-how is among the most important (Liu et al., 2021). Gherghel et al. (2019) summarized the available technologies in a review of wastewater sludge concerning the CE, emphasizing the processes available to recover valuable resources, including nutrients (e.g., phosphorus, protein), heavy metals, sewage sludge-based adsorbents, construction materials, bioplastics, and enzymes. Moreover, an impact analysis of innovative material recovery solutions discovered that benefit drivers for the adoption of these technologies are primarily sludge treatment savings, secondarily energy and carbon efficiency, and ultimately material recovery and reuse (Foglia et al., 2021). Nonetheless, water reuse and energy and nutrient recovery have not yet been commonly addressed in most large-scale WWTPs (Diaz-Elsayed et al., 2020).

Technological developments and successful adoption can serve as inspiration in the pursuit of CE (Flores et al., 2018). Nevertheless, implementing these technologies requires much effort, including reform of water management laws, regulatory systems, and capacity building. In this regard, Christodoulou and Stamatelatou (2016) point out that in the EU, sewage sludge is more narrowly defined as waste, while in the

Table 1
Actions for implementing a CE in the water and wastewater sector.

Action	Reference	Goal of the study	Key findings in brief
Decentralization			
	Capodaglio (2017)	To analyze needs, technological options and the contribution to water management of decentralized systems	Decentralized solutions tend to be compatible with local water use and reuse needs, where locally treated water could support agricultural productivity or be used as a substitute for potable water for compatible uses.
	Massoud et al. (2009)	To examine different decentralized approaches to wastewater treatment and management in developing countries.	The results show that although there are many obstacles to wastewater management in developing countries, these can be overcome with appropriate policy planning and implementation.
	Ghafourian et al. (2022)	To evaluate the economic viability of a hybrid decentralized rainwater- wastewater-greywater circular water system in an eco-tourist facility.	The findings show that the target system is economically feasible only after environmental and social benefits have been added to the assessment framework.
Digitalization			
	Eggimann et al. (2017)	To explore the potential of increased data availability to address today's challenges by making new and fundamental changes in how urban water management can be delivered.	Results demonstrate that data-driven urban water management provides an opportunity to develop and apply new methods, optimize the efficiency of the current network-based approach, and extend the functionality of existing systems.
	Liu et al. (2021)	To identify the most critical obstacles to the implementation of CE in the smart water management system in Zhejiang (China).	The findings reveal that obstacles related to recycling technologies, digital know-how and lack of CE awareness are the biggest concerns for implementing the circular economy in smart water management.
Resource recovery			
	Gherghel et al. (2019)	To perform a literature review regarding the wastewater sludge treatment processes and management used for its resouces and energy valorization.	They analyzed the types of sludge produced by WWTPs, the technologies to reduce sludge amount, as well as the conventional treatment and disposal methods.
	Foglia et al. (2021)	To assess the sustainability of co-innovative solutions which upgraded the existing WWTPs by following a holistic approach through economic, environmental, and social indicators.	Overall, the technologies created both environmental and social benefits, with a maximum relative total economic value of more than 20% compared to the baseline scenario.
	Diaz-Elsayed et al. (2020)	To identify trends in the environmental and economic effects of water, energy and nutrient recovery from wastewater and to study drivers contributing to these trends.	Resource recovery impacts tend toward economies of scale. Meaning, as more people are served (an increase in the scale of implementation) the life cycle impacts generally decrease.
Public interventions			
	Christodoulou and Stamatelatou (2016)	To examine the current legal frames and policies on sewage sludge management in different countries.	In most cases studied, legislation is moving toward exploiting sewage sludge's nutritive and energetic value.
	Guerrini and Manca (2020)	To determine actions that can be adopted by institutions that regulate the sector to encourage players to invest in CE and develop business policies based on environmental sustainability.	Identify possible forms of public intervention to encourage investments promoting the CE: market and governance reforms, strict legal provisions, and economic incentives.
	Romano et al. (2020)	To investigate a path-dependent regulatory process to establish a new method of calculating water tariffs for European regions and provinces that require context-specific regulation.	The evidence supports the use of various regulatory tools, following a contingent approach, to build diversified tariff structures.

United States and Australia, the term "biosolids" has more flexibly fostered the product's nutritive value. Three possible forms of public intervention exist to encourage investments that promote CE (Guerrini and Manca, 2020): market and governance reforms, strict legal provisions, and economic incentives. Market and governance reforms encompass several interventions across different segments of the supply chain, introducing new market platforms and actors. These reforms engage government entities that seek to generate value for the materials recovered by utilities implementing CE practices. The introduction of mandatory behaviors with an increased focus on environmental sustainability is also a widely adopted tool for the water sector (Bolognesi et al., 2022): for example, environmental limits set for effluent discharge and sludge disposal and mandatory green procurement. Economic incentives comprise various measures that enable utilities to recover resources and costs from investments in CE-based activities and maintain a margin. These measures are both regulatory and nonregulatory; for example, new tariff items introduced by regulators to recover extra costs incurred by utilities to develop CE-based activities or additional premiums allocated by public authorities for the achievement of environmental goals. In relation to the latter, Romano et al. (2020) highlight that it is achievable to simultaneously pursue compliance with national and international frameworks and respect contextual specificities by applying different regulatory instruments. Notwithstanding, Marques and Miranda (2020) and Massarutto (2020) pointed out that water pricing cannot serve "too many masters" and is not a "magic stick" that can solve all problems. In particular, the latter, analyzing water pricing for sustainability, emphasized that tariff design does not have a "one-size-fits-all" solution.

A key element in the evaluation of actions aimed at CE development is the analysis of the financial sustainability of such interventions (Smith et al., 2018). In this regard, Abu-Ghunmi et al. (2016) conducted a study in Jordan based on the opportunity cost of not "closing the loop" in the water industry. Nevertheless, to the authors' knowledge, no European studies have analyzed the financial sustainability of technology investments and facilitating factors to develop a CE in IWS companies.

2.1. European tariff systems and the circular economy

In recent years, the European Commission has paid increasing attention to CE dynamics in the water sector (e.g., Water Framework Directive, 2000/60/EC, Council Directive 91/271/EEC). Moreover, Pinto and Marques (2015) pointed out that water pricing is both an economic policy instrument and a powerful management tool that can be used to achieve the primary objectives underlying public service provision: economic efficiency, financial and environmental sustainability, equity and accessibility, and good governance – where the latter is reflected in the level of clarity and administrative ease (Molinos-Senante and Donoso, 2016). Thus, the selection of a tariff structure is a significant challenge, as it should meet the philosophy and goals of the company, the regulator, and the citizenry. Accordingly, in line with the increasing scarcity of water and the growing relevance of sustainability practices, water tariffs are seen as essential tools to achieve environmentally and economically efficient water use (Cooper and Crase, 2016; Reynaud and Romano, 2018; Romano et al., 2020).

According to WAREG (2019), a variety of tariff methods are used by European countries in the process of water pricing. The first of these is “Cost Plus,” a pricing method in which the customer pays the cost of providing the service plus a fixed percentage to the provider. This method is applied in countries such as Albania and Romania. Other countries, including Latvia and Estonia, have adopted a Rate of Return model – a modification of the “Cost Plus” approach in which limits are imposed on the rate of return on the invested capital. The third method is the “Price Cap”, and it is used for example in Hungary and Scotland. It sets a ceiling on the price charged to customers that is fixed for a specific period, after which it can be revised. A fourth method, “Revenue Cap” (fairly similar to “Price Cap”) eliminates demand risks, since any approved prices are adjusted for inflation, reduced by an efficiency coefficient, and further reduced or increased by a correction factor for the actual quantity sold (Barbosa and Brusca, 2015). This is an incentive as well as corrective regulation, in which producers that reach the mandated revenue ceiling are rewarded, while those that exceed it incur penalties. This method is applied for example in England and Wales. Other countries, such as Spain and Italy, have applied combinations of previous methods.

Related to the CE principle, the Water Framework Directive 2000/60/EC establishes the basic requirements for economic regulation of water services by introducing the principles of cost recovery, including environmental and resource costs and polluter pays. However, the directive does not provide detailed or operational rules for pricing methods. There are no requirements for the fee structure or for the process of fee application by the service provider and approval by a competent authority. Each member state treats this issue differently (WAREG, 2019). Therefore, the introduction of CE principles into tariffs is highly differentiated across European countries, and indeed, it is possible to identify countries that already have CE-related legislation (e.g., Italy). Other countries, such as Lithuania, are struggling to begin such a regulatory process, while others, such as France, have recently embarked (Guerra-Rodríguez et al., 2020). Regarding the latter, Barraqué (2020) highlighted the incoherencies and difficulties in creating incentives in the French tariff system that incorporate social and environmental aspects of sustainability. Hence, moving to a CE is not an obstacle-free process. Indeed, according to Abu-Ghunmi et al. (2016), the main barriers relate to incorrect resource pricing and lack of sufficient incentives to create effective measures. However, Italy, through its national water regulator (now called the Regulatory Authority for Energy, Networks, and Environment; ARERA), has changed tariffs to incentivize applying principles related to the CE framework. Accordingly, through recent measures (i.e., MTI-3), ARERA (2019) has implemented instruments aimed at overcoming water services gaps at the national level in the application of regulations and services, reducing management costs, improving environmental sustainability, classifying the sector within the economy, rewarding energy efficiency, and encouraging water saving and reuse. To achieve this, the authority has sought to define mechanisms to induce companies to aspire to progressive improvements, intending to ensure the environmental sustainability of the activities they manage and promote the use of innovative technologies to increase the reliability and safety of water infrastructure. This approach aims to make companies highly efficient with minimal environmental impact, following the ideals of the CE. Under the final provisions, tariff elements that involve aspects of environmental sustainability include:

- incentives to carry out water activities related to energy and environmental sustainability objectives
- incentives to reduce energy consumption
- compliance with the target for the technical quality indicator pertaining to the disposal of sewage sludge in landfill, as an indispensable condition for obtaining updated costs for the disposal of sewage sludge.

2.2. The Italian regulatory framework

According to Marques (2010), regulation of the Italian water industry began in 1965, although the most comprehensive reform did not begin until 1994, with the so-called Galli Law (Law No. 36 of 1994). Guerrini and Romano (2013) highlighted that this law had several objectives: to integrate water services (i.e., water supply and wastewater), to merge water utilities and allow the entry of private shareholders to increase the scale of the industry, to ensure that tariffs covered both current and capital costs, and to end the in-house supply of services by municipalities by franchising the provision of water services to independent operators (Carrozza, 2011; Danesi et al., 2007; Guerrini et al., 2011). Furthermore, this law imposed on every Italian region the obligation to define “optimal territorial areas” (Ambiti Territoriali Ottimali; ATO), to guarantee a geographical division according to natural water basins and to prevent over-fragmentation of services. As a result of the Galli Law, in 1996 a new system for setting water tariffs, known as the “normalized method,” was introduced by Ministerial Decree August 01, 1996. This method was based on the “average real tariff”; according to Carrozza (2011), it was effectively a form of revenue cap regulation. In the early 2000s, the new legal framework allowed franchises for the management of the national water and wastewater system to be granted either to private or mixed companies (on the condition that private partners were selected by public tender), or, alternatively, to publicly owned companies with in-house service provision.

In 2008, the planned improvements had not yet been fully implemented, despite some enhancements: many companies had integrated water and wastewater services and also provided gas, electricity, or industrial waste services. To implement the process of change started by the Galli Law, the Italian government, through Law No. 133 of 2008 (article 23 bis), mandated the privatization of public services, including water and wastewater services. In accordance with this new reform, water and wastewater services had to be franchised to private or public–private companies in which the private partner held at least 40% of the share capital; no water management licenses could be granted to public companies after December 2011 (Guerrini and Romano, 2013). In 2011, the referendum on these privatization-related changes led to further legislative changes. The result was that ATOs were no longer obliged to grant water and wastewater services concessions only to mixed or private companies; they could issue concessions to public companies financed by municipalities, as before the 2008 reform. In addition, the method of setting tariffs has changed: water tariffs no longer required to include a remuneration component for the capital employed (Guerrini and Romano, 2013).

In 2011, the Italian government established a new national water regulator (ARERA), in charge of defining a new tariff method to comply with EU principles (i.e., full cost recovery and “polluter pays”) and to provide uniform regulations at the national level (Romano et al., 2015).

In 2012, ARERA issued a transitional tariff method, the Metodo Tariffario Transitorio (MTT), and in 2013, developed a new standard method, the Metodo Tariffario Idrico (MTI), to be applied at a later stage. The MTI was developed in three subsequent versions: MTI, MTI-2, and MTI-3. The first measure (the MTT) was used during the transition from the previous ministerial tariff methodology (the so-called MTN-normalized tariff) to the new methodology. The transition path between the previous approach and the new tariff components was gradual (ARERA, 2012).

With the subsequent methodology (MTI), the authority adopted an innovative asymmetric adjustment, in which the local regulator was given a choice between several regulatory schemes. This choice was also given in relation to investment requirements, which corresponded to a different maximum level of tariff increase (ARERA, 2013).

The general approach of the MTI was confirmed with MTI-2 (ARERA, 2015), which introduced new elements to consider the need to promote investment, the sustainability of tariffs for users, and improvement of the (contractual) quality of service.

Through MTI-3, ARERA sought to implement additional measures to develop a CE in the water and wastewater sector. Accordingly, in the consultation document (ARERA, 2019; DCO 402/2019/R/IDR), the authority dedicated Chapter 5 to the discussion of “Promotion of measures for the energy and environmental sustainability of the integrated water services,” stating that:

the Authority is oriented to exploit innovative measures that can bring benefits in terms of containing overall costs, combining objectives of environmental protection and efficient recovery of valuable resources and energy (for example those aimed at recovering matter – nutrients such as nitrogen and phosphorus, cellulose, biopolymers, organic soil improvers—and energy from sewage sludge) (p. 36).

3. Materials and methods

3.1. The SMART-plant project and the SMARTechs

In its four years of implementation, the Horizon 2020 SMART-Plant project validated seven eco-innovative solutions defined as SMARTechs, aimed at the reduction of operational energy costs and related greenhouse gas (GHG) emissions from the WWTPs and recovery of energy, nutrients, and different bio-based materials. During the project, the SMARTechs were installed and operated in the same WWPTs in which they were originally developed in collaboration with the local integrated water utility, until they were fully validated under real environmental conditions. A brief description for each SMARTech covered by this study is given below:

SMARTech 1 consists of a primary treatment called Cellvation® (cell-vation.com) that separates cellulosic fibers from incoming sewage water and turns it into a clean and safe product named Recell® (recell.eu). Recell® is used to produce biocomposites and biopolymers or applied in asphalt, concrete, insulation, and other building materials. During primary treatment, a special Salsnes fine-sieve (www.salsnes-filter.com) separates cellulosic screenings from sewage water in a separate stage, which is then washed and further processed to gain clean cellulose fibers. Specifically, this technology was applied in two different settings: the first in Madrid (SMARTech 1a), the second in Berlin (SMARTech 1b).

SMARTech 2a consists of an anaerobic biofilter that combines the removal of soluble organic matter, suspended solids, and biogas production from municipal wastewater. This technology aims to reduce the organic load of the sewage by 30%, which reduces the energy consumption for aeration in the activated sludge process and energy recovery from the biogas utilization.

SMARTech 2b consists of a series of Sequencing Batch Reactors (SBRs) that accomplish via-nitrite nitrogen removal and simultaneous recovery of 50% of phosphorus and polyhydroxyalkanoates (PHA) enriched sludge with higher biogas production capacity. The system is built to achieve effluent limits of $P < 1$ mg/L and $N < 10$ mg/L, remove up to 90% of N via-nitrite, recover around 50% of the influent phosphorus, and produce a waste sludge with a PHA content of up to 30%.

SMARTech 3 consists of a tertiary nutrient removal and recovery technology based on ion exchange (IEX) processes. After secondary treatment, ammonia and phosphate are selectively removed from the wastewater with specific IEX media, achieving tight nutrient discharge limits by removing NH4+ and PO43- to very low concentrations (<5 mg N/L and <0.5 mg P/L) with high recovery rates: up to 97% of ammonia and 95% of phosphorus. The recovered products are ammonia solution and calcium phosphate salts, which can be directly re-used in the chemical and fertilizer industries. This technology was applied in two different settings: the first in Madrid (SMARTech 3a), and the second in Berlin (SMARTech 3b).

SMARTech 4a consists of a SBR for the removal of nitrogen and phosphorus from concentrated nitrogenous sidestream liquors using a short-cut biological process via-nitrite and volatile fatty acids (VFAs) produced from acidogenic fermentation of sewage sludge. The process avoids using an external carbon source, which decreases operational costs and excess sludge production. The system treats 40–50 m^3/d of anaerobic reject water, removing more than 75% of nitrogen and phosphorus. The excess sludge produced, with a phosphorus content of up to 5%, can be valuable for use as agricultural fertilizer.

SMARTech 4b consists of a SBR aimed at the biological removal of nitrogen and phosphorus via-nitrite from the sludge liquor obtained from the pre-treatment of sewage sludge by thermal and pressure hydrolyses process (THP) followed by anaerobic digestion.

SMARTech 5 consists of a series of SBRs aimed at the removal of up to 85% of nitrogen removal via-nitrite from the anaerobic sludge liquor with the recovery of PHA as precursors for bioplastics and struvite as source of phosphorus-based fertilizers. The peculiarity of this technology is the decrease in energy costs due to aeration by 20% and the recovery of PHA up to 1.2 kg PHA/capita and per year. In detail, this technology was applied in two different settings: the first in Carbonera (SMARTech 5a), the second in Berlin (SMARTech 5b).

A general overview of the SMARTechs, along with the products recovered/produced by the technologies and their benefits, is shown in Table 2 (Foglia et al., 2021).

Different settings were developed to evaluate the impact of each SMARTech according to their potential implementation in five real WWTP sites of different capacities, expressed as person equivalent (PE). More specifically, the seven SMARTechs were applied in 10 settings. Each setting was agreed on with the European Water Utilities as they considered their representative implementation according to specific local needs and were replicable at different sizes of sewage treatment plant. According to the classification of the European Environmental Agency (2020), four of the selected WWTPs referred to large or very large agglomerations (>150,000 PE), while one referred to a small agglomeration (<150,000 PE). A list of the selected WWTPs and their related treatment capacities are reported in Table 3.

3.2. Water tariff and simulation

This study adopts a tariff simulation to analyze the introduction of SMARTechs and assess their financial impact. A bottom-up approach is followed, using actual data from treatment plants. The simulation of Italian tariffs was developed through the ARERA tool (attached to Determination n. 1/2020 of 29 June 2020 as a reference), which comprises a spreadsheet made available to show the functioning of the tariff method.

Following MTI-3, the detailed formula for the composition of the guaranteed revenue amount (VRG) is as follows:

$$VRG = Opex + Capex + FoNI + Rc + ERC$$

where Opex refers to operating costs (e.g., the cost of personnel and raw materials). Capex is the capital expenditure tariff component (including for example depreciation of assets). FoNI is the new

Table 2
Overview of SMARTechs.

SMARTECH	Description	Advantages	Recovery Features
1	Dynamic rotating belt filter	Reduction of sewage sludge volume (up to 10%); reduction of WWTP energy consumption (up to 20%)	400 kg/d of pure marketable cellulose
2a	Innovative anaerobic biofilter	Reduction of organic load to the biological stage; reduction of sludge production (<20%) and energy consumption (up to 5–6%)	Increase of the WWTP biogas production (up to 15–25%)
2b	Mainstream SCEPPHAR (short-cut enhanced phosphorus and PHA recovery)	Removal of up to 86% of N	Recovery of phosphorus up to 45%; Production of PHA-rich sludge (up to 30% PHA in sludge)
3	Ion exchange tertiary treatment	Removal and recovery of nutrients (up to 85% of NH_4 and 95% of P); reduction of energy requirements (38%); reduction of GHG emissions up to 10–20%	Recovery of calcium phosphate salts up to 3.4 ton/year
4a	SCENA (short-cut enhanced nutrients abatement)	Nutrient removal (average equal to 78–80% for both N and P)	Production of P-rich sludge equal to 0.8–1 kg P/(PE·year)
4b	Thermal hydrolysis (THP) coupled with SCENA	Removal of high fractions of both N (>75%) and N–NH_4 (>90%)	Production of VFAs (0.9 kg COD_VFA/(PE·yr)
5	Sidestream SCEPPHAR	Removal of nutrients via nitritation up 80–90%, NO_2–N/NOx-N ratio >99%; reduction of energy requirements for sidestream treatment	Production of PHA-rich sludge (40–45 PHA%DM), and recovery of 1.0–1.2 kgPHA/(PE·yr); recovery of struvite

investment fund, RC is an adjustment for some components and the tariff's failure to obtain the VRG, and ERC represents environmental and resource costs attributable to endogenous, upgradable and technical quality costs.

Considering MTI-3, IWS companies that decide to adopt a SMARTech can ask local regulators to include it in their investment plan as "*Other water activities related to energy and environmental sustainability objectives point c)*," among the so-called b2 activities (ARERA Determination, 2020). In addition, though not clearly explained in MTI-3, the company may request an update to their endogenous operating costs for systemic changes that consider higher costs for other water activities. VRG would be enhanced by these two requests, considering not only the investment costs of activities related to environmental sustainability, but also the related operating costs.

Accordingly, investments in SMARTechs cause a change in Capex; they become assets for the company and produce a change in operating costs (Opex and Rc) because they generate different energy, sludge disposal, and chemical costs. Therefore, the simulation based on the MTI-3 tariff regulation is conducted by calculating the Opex, Capex, and Rc tariff components and setting VRG equal to their sum:

VRG = Opex + Capex + Rc.

Moreover, the length of the tariff plan is set at 20 years, corresponding to the useful life of the treatment plant.

In the simulation schemes, the measure of the effect on the company's profit, "impact on the IWS company," is given by:

50% * OFin + max (0; [75% {Revenues b2 – Costs b2}] * (1–24%))

where:

- OFin is the quantification of financial charges linked to the investment value. This value is taken at 50% because the tariff method parametrically provides that the ratio between equity and debt capital is equal to one, and therefore 50% of the financial charges are designed to cover the banks' financial charges, with the other 50% as remuneration for shareholders' capital
- 75% is used as the company obtains recognition of 75% of the profit achieved in a given year with a time delay of two years through the tariff adjustment component *Rc Activity b)*
- 24% represents the Italian corporate income tax.

Starting from this formula, a summary of the items presented in Table 4 will be analyzed.

Specifically, the economic effect on the company will be assessed by producing an estimate of the change in net present value (NPV, in millions of euros (M€)), internal rate of return (IRR), and payback period (PP). In particular, NPV is the present value of the cash flow at the required rate of return of the project compared with the initial

Table 3
WWTPs selected for the implementation the SMARTechs.

WWTP site	Country	Plant capacity (PE)	Collection sources	Type	SMARTech
Madrid	Spain	1,612,800	N/A	Very large agglomeration	SMARTech 1a SMARTech 3a
Karmiel	Israel	250,000	Residential from 13 municipalities	Large agglomeration	SMARTech 2a
Berlin	Germany	1,000,000	Water from toilet flushing; Kitchen water with leftover food; Cleaning and bathing water; Industrial and commercial wastewater; Surface water with the dirt from roofs, courtyards, gardens, roads and squares	Very large agglomeration	SMARTech 1b SMARTech 3b SMARTech 4b SMARTech 5b
Manresa	Spain	196,167	Residential	Large agglomeration	SMARTech 2b
Carbonera	Italy	50,000	Residential from 8 municipalities	Small	SMARTech 4a SMARTech 5a

Table 4
Items analyzed.

Item	Description
NPV (M€)	NPV of the annual component "impact on the IWS company"
IRR (%)	Internal rate of return on investment calculated on annual cashflows
Payback period	Years required for recovery of initial investment

investment (Bowhill, 2008), which, in practical terms, provides a method for calculating the return on investment (ROI) for a project or expenditure (Gallo, 2014). In addition, IRR is the discount rate that sets NPV equal to zero. The IRR decision criterion suggests accepting a project if and only if the IRR is greater than the cost of capital (usually, the market rate) and to rank competing projects via their IRR: the higher a project's IRR, the higher its rank (Magni, 2010). PP is the time expected for an investment project to recoup its initial cost (Weingartner, 1969); therefore, the lower the PP, the better the investment. For the detailed tariff composition and intermediate simulation results, see Appendix.

In addition, the analysis will be conducted in duplicate, assuming two different scenarios related to the start (or not) of the SMARTech product market: Scenario A is characterized by the presence of such market, while Scenario B represents its absence. Moreover, Scenario A was carried out under the assumption of the presence of a centralized broker, allowing the creation of a platform for matching supply and demand, which, according to AquaMinerals (2018) and Ofwat (2021), offers the best starting point to give life to and to stabilize such market. Indeed, the presence of a broker that supplies materials to the market and stipulates multi-year agreements would reduce the financial risk for IWS companies.

4. Results and discussion

The results for a single SMARTech within Scenario A (featuring the presence of a SMARTech market) are presented in Table 5.

Scenario A (Table 5) shows that the impact is positive for all SMARTechs. In particular, NPV (M€) is highest for SMARTech 3 (3a and 3b), with a positive difference of 43.33 M€ and 27.19 M€ respectively, due to the potential high value of the SMARTech products. Indeed, this scenario could be achieved if a stable market were established for this product. However, the difference is not marked for SMARTech 4a, because higher benefits in terms of energy savings are expected when this technology is implemented in large WWTP. On the other hand, energy savings may not be evident when the biological treatment of the existing WWTPs is already highly efficient. This could explain why the IRR analysis shows that SMARTech 4b has the lowest rate. However, concerning recovery time, similar to the IRR analysis, the most significant benefits are gained with SMARTech 5a.

Results for Scenario B, characterized by the absence of a market for the sale of products, are shown in Table 6.

In this scenario, there is no market for products resulting from using SMARTechs. Table 6 shows that, although there are no differences in IRR and PBP, there may be significant benefits in terms of NPV. The two most relevant cases are where SMARTech 3 (3a and 3b) are implemented, because this may imply the need to revamp existing WWTP with higher reaction volumes is avoided, generating savings in terms of electrical energy and sludge reduction.

From this simulation of the impact on tariff policy of the introduction of SMARTech technologies, it is evident that the impact on the IWS company is positive.

As can be seen from Table 7, in both scenarios, companies draw an advantage from including SMARTechs. In particular, analyzing the NPV of Scenario A, it can be seen that in the presence of SMARTechs, the average result is 36.54 M€, which drops to 23.99 M€ when the technology is absent. Furthermore, even in Scenario B, the impact on the company (i.e., NPV) is 27.22 M€ if SMARTechs are present and 24.2 M€ if not. Clearly, the results vary for each individual SMARTech. Indeed, in Scenario A, SMARTechs 3 (3a and 3b) generate an impact of 72.33 M€ and 69.73 M€, respectively, while 4a and 5a generate an impact of 0.10 M€ and 1.04 M€ respectively (Table 5). The reason for this lies in the fact that the treatment capacity of the WWTP where these SMARTechs are installed affects the productivity of the bio-based products that can be recovered; the higher the treatment capacity of the WWTP, the higher the net potential savings in terms of electrical energy combined with the related revenue from the bio-based products sold in the market. Moreover, the results vary according to the SMARTech under analysis even for Scenario B. For instance, SMARTech 3b obtained an NPV of 51.87 M€, while SMARTech 5a obtained a result of 0.10 M€. In addition, the most significant impacts resulting from the introduction of SMARTechs in terms of the IRR and PBP analysis only occur in Scenario A. When the IWS company can place products derived from a SMARTech on the market, the IRR of the investment increases further, from a minimum of 0.03% for SMARTech 4b to a maximum of 13.04% for SMARTech 5a (Table 6).

Resource recovery and safe reuse of secondary raw materials recovered from residual cycles can improve sustainability (Akyol et al., 2020) and ensure social wellbeing and economic growth, while reducing environmental impacts and risks (Lazurko, 2018). Moreover, Nika et al. (2020) believe successful implementation of a CE in the wastewater sector requires innovations fostered through the economic and social context. In line with this, the financial benefits obtained with the inclusion of each SMARTech are higher or at least equal to the results obtained without this inclusion under both scenarios. These results highlight the advantages for IWS companies in adopting this technology, from a strictly business perspective.

The environmental impact assessment is presented in Table 8. Foglia et al. (2021) and SMART-Plant (2020) highlight that the results depend on each SMARTech. Here, the possible reduction in greenhouse gas emissions ranges from 7% (SMARTech 5) to 71% (SMARTech 3), while the possible reduction in energy demand ranges from a minimum of 4% (SMARTech 1) to a maximum of 68% (SMARTech 2a).

5. Conclusion

SMART-Plant is a European project that validates eco-innovative solutions for upgrading WWTPs into water recovery facilities through innovative technologies (i.e., SMARTechs) that differ in their recovery features and advantages. This study evaluates SMART-Plant from a financial perspective, via a simulation of the MTI-3 tariff regulation. This was carried out under the hypothesis of the inclusion of SMARTechs by the company (and the associated costs) and then under the hypothesis of the non-inclusion of this innovative technology. The analysis was executed under two scenarios: the presence of a market for the sale of products derived from this technology, and the absence of such market.

The findings of this paper, which assessed the sustainability of technology investments and facilitating factors to develop a CE in IWS companies from a financial standpoint, have theoretical and practical implications for the CE and water sector literature. From a managerial perspective, this study highlights the advantages for IWS companies in adopting SMARTechs, not only for environmental sustainability purposes, but to pursue economic objectives, in line with Resolution 71/222, which states that "the objectives of the decade should be a greater focus on the sustainable development and integrated management of water resources for the achievement of social, economic and environmental objectives." In addition, the results emphasize the factors that enhance the implementation of such technologies. In fact, the analysis highlights that the presence of a market for products resulting from the implementation of SMARTechs is crucial for increasing the profitability of the investment. Thus, legislation or funding mechanisms should support the recovery of bio-based nutrients and materials from WWTPs.

Table 5
Results of scenario A

Type of SMARTech	SMARTech 1		SMARTech 2a	SMARTech 2b	SMARTech 3		SMARTech 4a	SMARTech 4b	SMARTech 5	
Setting	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b
Without SMARTech										
Opex (M€)	300	146	51	19	146	300	9	300	9	300
Capex (M€)	246	168	56	12	168	246	0	246	0	246
Rc (M€)	0	0	0	0	0	0	0	0	0	0
VRG (M€)	546	314	107	31	314	546	9	546	9	546
Other revenue (M€)*	0	0	0	0	0	0	0	0	0	0
NPV (M€)	42.54	29.00	9.67	2.03	29.00	42.54	0.04	42.54	0.04	42.54
IRR (%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%
PP (years)	13	13	13	13	13	13	13	13	13	13
With SMARTech										
Opex (M€)	281	144	51	18	137	245	9	293	9	296
Capex (M€)	254	180	66	13	251	299	1	252	1	252
Rc (M€)	11	19	2	3	38	24	0	0	1	25
VRG (M€)	547	344	119	34	426	568	9	545	10	573
Other revenue (M€)*	27	46	3	4	47	29	0	0	2	32
NPV (M€)	52.25	45.95	13.07	4.76	72.33	69.73	0.10	43.74	1.04	62.40
IRR (%)	5.89%	6.42%	5.80%	7.45%	6.77%	6.19%	5.57%	5.54%	18.55%	6.34%
PP (years)	12	12	12	11	12	12	13	13	7	12
Difference										
Opex (M€)	−18	−2	−1	−2	−9	−55	0	−7	0	−3
Capex (M€)	8	13	10	2	83	53	0	6	0	6
Rc (M€)	11	19	2	3	38	24	0	0	1	25
VRG[a] (M€)	1	30	12	3	112	22	0	−1	1	27
Other revenue (M€)*	27	46	3	4	47	29	0	0	2	32
NPV (M€)	9.72	16.95	3.40	2.73	43.33	27.19	0.06	1.20	1.00	19.86
IRR (%)	0.38%	0.91%	0.29%	1.94%	1.26%	0.68%	0.06%	0.03%	13.04%	0.83%
PP (years)	−1	−1	−1	−2	−1	−1	0	0	−6	−1

Note: * Revenue from other water activities related to energy and environmental sustainability objectives (M€).

Table 6
Results of scenario B.

Type of SMARTech	SMARTech 1		SMARTech 2a	SMARTech 2b	SMARTech 3		SMARTech 4a	SMARTech 4b	SMARTech 5	
Setting	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b
Without SMARTech										
Opex (M€)	300	146	51	19	146	300	9	300	9	300
Capex (M€)	246	168	56	12	168	246	0	246	0	246
Rc (M€)	0	0	0	0	0	0	0	0	0	0
VRG (M€)	546	314	107	31	314	546	9	546	9	546
Other revenue (M€)*	0	0	0	0	0	0	0	0	0	0
NPV (M€)	42.54	29	9.67	2.03	29	42.54	0.04	42.54	0.04	42.54
IRR (%)	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%
PP (years)	13	13	13	13	13	13	13	13	13	13
With SMARTech										
Opex (M€)	281	144	51	18	137	245	9	293	9	296
Capex (M€)	254	180	66	13	251	299	1	252	1	252
Rc (M€)	0	0	0	0	0	0	0	0	0	0
VRG (M€)	536	325	117	31	388	544	9	545	9	548
Other revenue (M€)*	0	0	0	0	0	0	0	0	0	0
NPV (M€)	44.1	31.25	11.48	2.32	43.52	51.87	0.1	43.71	0.1	43.71
IRR (%)	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%	5.51%
PP (years)	13	13	13	13	13	13	13	13	13	13
Difference										
Opex (M€)	−18	−2	−1	−2	−9	−55	0	−7	0	−3
Capex (M€)	8	13	10	2	83	53	0	6	0	6
Rc (M€)	0	0	0	0	0	0	0	0	0	0
VRG (M€)	−10	11	10	0	74	−1	0	−1	0	3
Other revenue (M€)*	0	0	0	0	0	0	0	0	0	0
NPV (M€)	1.56	2.25	1.81	0.3	14.52	9.33	0.06	1.17	0.06	1.17
IRR (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
PP (years)	0	0	0	0	0	0	0	0	0	0

Note: * Revenue from other water activities related to energy and environmental sustainability objectives (M€).

End-of-waste process decisions in EU countries could promote these technologies to encourage transfer among the water sectors. On the other hand, the generated bio-based products must be top quality, to beat the alternatives already available on the market or to be suitable for further applications. In this regard, the results suggest policy makers should develop a regulatory approach to promote the market for these products to enable and encourage their use. Accordingly, policy makers could, for example, take their cue from the U.K.; indeed, with the PR19 reforms (Ofwat, 2021), it has taken a huge step in that direction. Moreover, at the European level, it is recommended to identify and require IWS companies to achieve a minimum amount of recovery to generate subproducts. By including this obligation, companies that do

Table 7
Summary of average results.

		Market for the sale of products			
		Presence		Absence	
SMARTechs	**Presence**	NPV (M€)	36.54	NPV (M€)	27.22
		IRR (%)	7.45	IRR (%)	5.51
		PP	11.60	PP	13
	Absence	NPV (M€)	23.99	NPV (M€)	23.99
		IRR (%)	5.51	IRR (%)	5.51
		PP	13	PP	13

Table 8
Environmental impact of SMARTechs.

SMARTECH	Resource recovered from WWTP	Energy and carbon footprint reduction
1	Cellulose recovery: 2.3–7.9 kg/PE per year	Reduction of energy demand by 4–23% Reduction of GHG emissions up to 19%
2a	Methane production: 3.0–5.5 liter/PE per year	Reduction of energy demand by 62–68% Reduction of GHG emissions up to 22%
2b	PHA excess sludge: 1.8 kg/PE year Struvite: 1.4 kg/PE year	Reduction of energy demand up to 18% Reduction of GHG emissions up to 12%
3	Recovery of up to 69% of the nitrogen and 78% of the phosphorus influent	Reduction of energy demand up to 52% Reduction of GHG emissions up to 71%
4a/4b	Reduction of the N load up to 76%	Reduction of energy demand up to 10%
5	Recovery of PHA: 1.0–1.2 kg PHA/PE per year Recovery of P: around 0.5 kg/PE year	Reduction of energy demand up to 8% Reduction of GHG emissions up to 7%

not reach this target are sanctioned or must buy this quantity from another company. This mechanism could foster and develop the transition from a linear to a circular economy.

In addition, the analysis of the Italian tariff policy and its regulatory evolution highlights which tenets have been adopted and what steps have been implemented to incentivize a CE in the water and wastewater sector. This analysis may guide policy makers of countries struggling to develop a CE in this sector.

Notwithstanding, this study has limitations. For instance, the analysis of Scenario A overlooks the possibility that IWS companies may sell their products individually to the end user. In addition, the results do not consider the additional advantages for IWS companies due to sharing their reduction in electrical energy consumption or the awards and penalties related to achieving technical quality standards. Further studies are necessary to overcome these limitations. Moreover, an important element for future research concerns water companies' challenges in managing and maintaining these new technologically complex assets, i.e., SMARTechs. Also, these technologies' impact on business models should be more thoroughly investigated. To this end, additional case studies and qualitative evidence of complexity management from both academia and the water industry are needed. In addition, it should be noted that the introduction of technologies also affects users. Furthermore, future research could conduct financial analyses through a simulation based on a different tariff system. From a benchmarking perspective, this would allow a better understanding of these technologies' impacts on different tariff systems and identify which incentive mechanisms are most effective to foster a CE.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix. Italian Tariff Methodology and Simulation

The tariff regulation provides that water tariffs[1] have to be adequate annually with a multiplier (called "theta") determined in such a way to allow the INTEGRATED WATER SERVICE company to obtain an overall amount called—guaranteed revenue amount (VRG). This corresponds to the sum of the tariff components deemed admissible by the same tariff methodology and is linked to the operating and investment costs of the activities classified as INTEGRATED WATER SERVICE and "other water activities" (Table 1). Costs of investment and operation of the other non-water activities, carried out by the INTEGRATED WATER SERVICE company with the use of the INTEGRATED WATER SERVICE infrastructure, are not part of the VRG.

Table 1
Water tariff methodology for the third regulatory period.

Type	Description
INTEGRATED WATER SERVICE	Consists of all public services for the collection, supply and distribution of water for civil use, for sewerage and purification of wastewater, or each of the aforementioned individual services, including multiple-use collection and adduction services, and purification services for mixed civil and industrial uses. Also includes: a) the construction of water and sewage connections, which consist of water and sewage pipes derived from the main system and dedicated to the service of one or more users; installation of the relative accessories, network separations, removal of the socket points and construction of junction wells b) the collection and removal of rainwater and urban drainage through the management and maintenance of dedicated infrastructures (white sewers), including cleaning and maintenance of road drains; however, for the purpose of

(continued on next page)

[1] This refers to the variable and fixed tariffs for the water supply, sewerage, treatment and ancillary services, such as contractual transfers, contractual activation etc.

Table 1 (*continued*)

Type	Description
	determining tariffs where not already included in the INTEGRATED WATER SERVICE at the date of publication of this provision, these activities are considered "non-water activities that also use integrated water service infrastructures" c) the performance of services and ancillary services account users, such as activation, deactivation and reactivation of the supply, the transformation of use, transfers, transfers of supply, preparation of estimates, readings of one-off inspections and audits d) the transport and sale of water by tanker or other road vehicles in emergency situations
Other water activities (so-called b)	The set of activities relating to water services, including those relating to energy and environmental sustainability objectives, other than those included in the INTEGRATED WATER SERVICE; in particular: a) the performance of other water supplies, such as the sale, with dedicated infrastructures, of non-drinking water or water for industrial, agricultural or sanitary use, the transport and sale of water by tanker or other road vehicles for non-emergency situations, the installation and management of "water houses", the installation and management of fire vents, the reuse of purification water b) the performance of other waste collection and treatment activities, such as the management of industrial sewers with dedicated infrastructures, purging of cesspools, treatment of leachate from landfills and treatment of liquid waste or spoils c) the execution of works on behalf of third parties for the construction of infrastructures of the INTEGRATED WATER SERVICE, which consists of the realization of infrastructures of the INTEGRATED WATER SERVICE on behalf of another subject who has entered these infrastructures as assets d) the performance of other works and services for third parties, related, connected or attributable to water services, regardless of whether they are provided for a person who does not manage water services, such as the construction and/or maintenance of the systems downstream of the meters, cleaning of fountains, reading of the divisional counters inside the condominiums, preliminary investigation and inspection to issue/renew drain authorizations and to issue preventive opinions for private sewage systems, preliminary investigation, testing and release of technical acceptability opinion for urbanization and connection works carried out by third parties, laboratory analyzes, design and engineering and other similar works and services e) collection includes the collection and distribution of the tariff by the aqueduct operator in the event that the INTEGRATED WATER SERVICE is managed separately pursuant to Article 156 of *Legislative Decree 152/06*
Non-water activities that also use INTEGRATED WATER SERVICE infrastructures	They consist of different activities from water services but also those carried out through the use of infrastructure of water services, such as the sale of electricity, promotion of biogas of sewage treatment plants, if not already included in other water treatment activities, use of water pipes for housing data transmission infrastructures, rental of infrastructures for cabling activities or installation of transceiver antennas, construction of works and/or services for third parties not related to water services and other similar activities

Source: Resolution 580/2019/R/idr - Water tariff methodology for the third regulatory period (MTI-3)

The INTEGRATED WATER SERVICE company must cover the overall costs of the service with the revenues it obtains from the application of the water tariffs updated with the theta and from the revenues obtained from the performance of further water activities it can perform with the infrastructure of the service.

(Water tariff + revenues from other water activities) * teta = VRG.

In the tariff plan, the above concept is represented as in Table 2:

Table 2
Water tariff methodology for the third regulatory period

A	VRG^a	Cap amount on guaranteed revenues
B	R_b^{a-2}	Revenues from other water activities
C	$tariff^{2019} * vscal^{a-2}$	Revenues from water tariffs
D = A/(B + C)	ϑ^a	**Teta**

In terms of a detailed composition of VRG, Table 3 summarizes the eligible tariff components and its sub-components.

$VRG = Opex + Capex + FoNI + Rc_{TOT} + ERC$.

Table 3
Tariff components and sub-components

Cost components (category)	Specific cost components	Description
Opex	$Opex_{end}^a$ (net of ERC)	The so-called endogenous costs fixed in a stable measure and subject to inflation adjustment only. For example, the cost of personnel and raw materials is included in this category
	$Opex_{al}^a$ (net of ERC)	The so-called exogenous costs that are adjusted on the basis of the final values of previous years. For example, the cost of electricity and local taxes belong in this category
	$Opex_{QC}^a$	The costs that from 2016 have been recognized to the companys for the adaptation of the service rendered to the minimum contractual quality standards set by AUTHORITY FOR ELECTRICITY AND GAS
	$Op^{new,a}$	The additions to the charges OPEX end tied to specific situations of significant expansion of the service supplied
	$Opex_{QT}^a$ (al netto degli ERC)	The costs that from 2018 have been recognized to the managers for the adaptation of the service rendered to the technical quality standards set by AUTHORITY FOR ELECTRICITY AND GAS
	Op_{social}^a	The cost of the integrative bonus for tariff concessions to support situations of social and economic hardship established locally according to the needs of the territory. These are additional appropriations to those of the national water bonus
Capex	AMM^a	The amortization of the invested capital calculated by applying the Useful Lives defined by AUTHORITY FOR ELECTRICITY AND GAS
	OF^a	The financial charge recognized on the capital invested calculated by applying the financial parameters defined by AUTHORITY FOR ELECTRICITY AND GAS

(*continued on next page*)

Table 3 (*continued*)

Cost components (category)	Specific cost components	Description
	$OFisc^a$	The tax charge recognized on the invested capital calculated by applying the financial parameters defined by AUTHORITY FOR ELECTRICITY AND GAS
	$\Delta CUIT^a_{Capex}$	concerns the enhancement of third-party infrastructures with respect to the fees allowed in the $OPEX_{al}$. For example, assets purchased under leasing are valued through this cost category
FoNI	FNI^a_{FoNI}	One of the three components that feed the FoNI (New Investments Fund). FoNI is a financial advance for the realization of investments. The FNI component is fueled by the difference between the planned investments and the available Capex
	AMM^a_{FoNI}	One of the three components that feed the FoNI (New Investments Fund). This component is linked to non-repayable contributions (CFP)
	$\Delta CUIT^a_{FoNI}$	One of the three components that feed the FoNI (New Investments Fund). FoNI is a financial advance for the realization of investments. This component is linked to the presence mainly of municipal assets not yet fully depreciated
$\mathbf{RC_{TOT}}$		The adjustments recognized on some components and on failure to obtain the VRG from the tariff. It is calculated by comparing the expected and final balance. For example, the adjustment on electricity costs, wholesale purchases etc.
ERC	ERC^a_{end}	Part of the environmental and resource costs (ERC) attributable to endogenous costs
	ERC^a_{al}	Part of the ERC attributable to upgradeable costs
	$ERC^a{}_{QT}$	Part of the ERC attributable to technical quality costs

While operating costs have tariff coverage in the current year (except for any subsequent adjustments), the capital invested is recognized in the tariff with a time lag of two years.

The VRG and its components are verified biennially: if there is no identity between what the INTEGRATED WATER SERVICE company obtained from the application of tariffs and the total VRG, two years after an adjustment is determined that feeds the component $Rc_{TOT.}$

In the final provision (580/2019/R/idr), the tariff elements that involve aspects of environmental sustainability are:

- the incentive to carry out other water activities related to energy and environmental sustainability objectives
- the incentive to reduce energy consumption
- compliance with the objective of the technical quality indicator M5, relating to the disposal of sewage sludge in landfills, as an indispensable condition for obtaining the updating of costs for the disposal of sewage sludge.

Regarding the first aspect, the authority predicted that within the activities classified as "*other water activities*"—also defined as "b activities"—would have to be individualized a specific subcategory: "*other water activities related to energy and environmental sustainability*"—also defined as "b2 activities" —characterized by the recognition of a level of profit sharing of 75% in favor of the company. These activities are selected by the relevant governing body of the area, and may include:

a) energy efficiency in activities and infrastructures if not attributable to the integrated water service;
b) the reduction of the use of plastic through the promotion of drinking water consumption also through the installation of drinking fountains;
c) the recovery of energy—electrical and thermal—and raw materials through plants or specific treatments integrated into the water infrastructure, as well as the diffusion of energy from renewable sources for the supply of the integrated water service plants;
d) the reuse of treated water (for example for agricultural and industrial purposes) to promote greater rationalization of the resource, in particular in contexts characterized by drought.

The company obtains recognition of 75% of the profit achieved in a given year with a time delay of two years through the tariff adjustment component *Rc Attivit*à *b* (referred to in paragraph 27.1 of the MTI-3).

The company has an incentive to carry out the "other water activities" with the use of infrastructure. This is because if the INTEGRATED WATER SERVICE follows the profits ($R_b^{a-2} > C_b^{a-2}$) from such categories, a part of them rim ring in its availability as an increase in the standard rate of return on invested capital. Conversely, if the company does not obtain profit ($R_b^{a-2} < C_b^{a-2}$), the company has the advantage of not being financially accountable for the risk of the underlying operating costs and investment. These are part of VRG, so are covered by the tariffs.

As far as electricity is concerned, the first measures aimed to contain the related costs were introduced by the authority in 2014, providing for a maximum threshold for to be recognized for tariff purposes. To incentivize companies to pursue energy saving objectives, a cost sharing factor has been proposed. This would apply to the component of electricity costs CO_{EE} (see Article 20 of the MTI-3) based on the difference between consumption of electricity recorded in the last year and the average level of consumption measured in the previous four years:

$$CO^a_{EE} = \left\{ min\left[CO^{effettivi,a-2}_{EE}; \left(\overline{CO^{medio,a-2}_{EE}} * kWh^{a-2}\right) * 1,1\right] +_{EE} * {}^a_{Risparmio} \right) \right\} * \prod_{t=a-1}^{a} \left(1 + I^t\right)$$

where:

- $CO^{effettivi,a-2}_{EE}$ is the total cost of the electricity supply incurred two years before the year of tariff determination by the INTEGRATED WATER SERVICE company, or in the last year for which the approved budget is available.
- $\overline{CO^{medio,a-2}_{EE}}$ is the average sector cost of the electricity supply incurred during the year ($a-$ 2).
- kWh^{a-2} is the electricity consumption sustained two years before the INTEGRATED WATER SERVICE company.
- $\prod_{t=a-1}^{a} (1 + I^t)$ is the producer of inflation rates.
- ${}^a_{Risparmio}$ is the saving in the cost of electricity supply achieved by the company as a result of energy efficiency measures, defined as:

$$ {}^{a}_{Risparmio} = \left(\frac{\sum_{n=3}^{6} kWh^{a-n}}{4} - kWh^{a-2} \right) * \min \left(\frac{CO_{EE}^{effettivi,a-2}}{} kWh^{a-2};\ \overline{CO_{EE}^{medio,a-2}} * 1,1 \right) $$

- $_{EE}$.
  - $_{EE} = 0$, se ${}^{a}_{Risparmio} < 0$.
  - $_{EE} = 0{,}25$, se ${}^{a}_{Risparmio} > 0$.

In cases in which the consumption of the last year is less than the average measured in the four previous years, the eligible energy cost for the company is integrated with an amount equal to 25% of saving of cost obtained by the reduction of consumption. The application of this mechanism implies the presence of energy efficiency interventions in the interventions program (PdI) prepared by the EGA.

Regarding the disposal of sludge in landfills, in 2019, ARERA Determination (2020) initiated a fact-finding survey on the mode of treatment, recovery and disposal of sludge arising from wastewater treatment "to favor the diffusion of solutions innovative technologies aimed at recovering matter from sludge, as well as, more generally, accompanying and further stimulating the transition to a circular economy in the purification sector".

Specifically, with resolution 917/2017/R/IDR (RQTI), AUTHORITY FOR ELECTRICITY AND GAS identified the macro-indicator M5— "Disposal of sludge in landfills" (which is associated with the objective of minimizing the environmental impact connected to the treatment of waste). This is defined as a percentage ratio between the annual quantity of sewage sludge disposed of in the landfill and the amount of sewage sludge produced in all sewage plants in the area under the responsibility of the company in the same year, both expressed in terms of dry substance.

Article 18 of the resolution provides that each company is required to pursue the macro-indicator M5 annual targets, divided into objectives of "improvement" (i.e., the total reduction of sludge intended to landfill disposal) and "maintenance" (if the value assumed by the macro-indicator M5 is below the established threshold of 15%).[2] The 917/2017/R/IDR does not allow planning of investments that do not involve the achievement of the objectives above defined.[3]

Article 22 of MTI3 provides that the company is recognized for the higher costs for the disposal of sewage sludge, provided that the objective of improvement or maintenance associated with the macro-indicator M5 "Disposal of sludge to landfill" is achieved.

Further, bonuses and penalties are associated with the achievement of the improvement or maintenance objective related to the macro-indicator M5, which, currently, does not yet affect the company's returns but which will be activated with subsequent measures.

The simulation of the MTI-3 tariff regulation was conducted by calculating the Opex, Capex and Rc tariff components and placing the VRG equal to:

VRG = Opex + Capex + Rc.

The component OPEX comprises several types of costs:

- personnel costs
- energy costs
- sludge disposal costs
- chemicals costs
- maintenance costs.

Operating costs are not distinguished between endogenous and updatable costs (in which the "energy costs" should be placed) since the simulation was conducted with forecast data.[4] The incentive component for savings in electricity consumption envisaged by the MTI3 was also not calculated.

Operating costs are expected to be constant without any assumption regarding their temporal trend. Further, inflation, which pursuant to Article 6 of the MTI-3 adjusting the operating costs for the purposes of calculation of OPEX, has been set equal to 0%.

The Capex component is determined with the following assumptions

- The investment is made and placed into operation in just one year (2020);
- The deflator, pursuant to Article 6 MTI-3, revalued the investment for the purpose of calculating the Capex was set equal to 1.

Depreciation was calculated on the basis of the formula (see Article 10.1 of MTI 3).

$$ AMM^{a} = \sum_{c} \sum_{t}^{2011} \min \left(\frac{IP_{c,t} * dfl_{t}^{a}}{VU_{c,t}}; IMN_{c,t}^{a} \right) + max \left\{ 0;\ \sum_{c} \sum_{2012}^{a} \min \left[\frac{IP_{c,t} - CFP_{c,t}}{VU_{c,t}} * dfl_{t}^{a}; \left(IMN_{c,t}^{a} - \left(CFP_{c,t} * dfl_{t}^{a} - FA_{CFP,c,t}^{a} \right) \right) \right] \right\} $$

[2] The aforementioned value of 15%, identified to determine the class of excellence for macro-indicator M5, was derived from a comparison between the national average figure and the European average on the use of landfilling, and was determined by the authority as a target achievable in all medium–long-term management.

[3] With reference to the need for investments to increase the recovery of material and energy from the sewage sludge (minimizing the use of landfill disposal), starting from values substantially contained in the first years, a trend that tends to grow in the 2016–2019 four-year period (from €0.09/inhabitant in 2016 to €0.56/inhabitant in 2019), with interventions planned after 2019 corresponding, overall, to €3.27/inhabitant. In this regard, among the most recurrent interventions in planning, there are interventions to adapt or enhance existing sections (e.g., measures for the optimization of the anaerobic digestion of sludge sections on individual plants and interventions to improve efficiency of the mechanical dehydration process) and the construction of new plants (to introduce a centralized drying phase and solutions for the energy enhancement of sludge).

[4] No final data are foreseen with which to calculate the adjustments.

In the case of the simulation object, for the presence of a single investment whose realization is assumed entirely in 2020 and by the absence of grants (CFP^{a}_{fp})and related funds depreciation (FA^{a}_{CFP}), formula is transformed in:

$$AMM^{a} = max\left\{0;\ \sum_{c}\sum_{2020}^{a} \min\left[\frac{IP_{c,t}}{VU_{c,t}} * dfl^{a}_{t};\ \left(IMN^{a}_{c,t}\right)\right]\right\}$$

where:

$AMM^{a}$is depreciation

$IP_{c,t}$is the annual investment increase

$VU_{c,t}$ is the regulatory useful life

dfl^{a}_{t} is the deflator

$IMN^{a}_{c,t}$ is the net invested capital

The investment is subject to technical depreciation and not to the financial. The regulatory useful life $VU_{c,t}$ is identified based on the categories of immobilization defined in MTI3 as specified in the Table (Regulatory techniques useful lives).

Table 4
Regulatory techniques useful lives

Category of fixed assets	VUc, t	SMARTech 1a	SMARTech 1b	SMARTech 2a	SMARTech 2b	SMARTech 3a	SMARTech 3b	SMARTech 4a	SMARTech 4b	SMARTech 5a	SMARTech 5b
Sewage lifting and pumping systems	8										
Natural purification techniques (including phytodepuration and lagooning)	40										
Purification plants—treatment until the preliminary, supplemental, primary septic tanks and was Imhoff	20										
Purification plants—treatments up to secondary	20	✓	✓	✓	✓			✓	✓	✓	✓
Purification plants—treatments up to the tertiary and advanced tertiary sectors	20					✓	✓				
Sludge drying and enhancement plants (including mono-incineration, pyrolysis, gasification)	20										
Measuring groups—other purification equipment	10										
Purification information systems	5										
Remote control and remote transmission of purification	8										

Financial costs were calculated on the basis of the formulas pursuant to Article 11 of the MTI 3:

$$OF^{a}_{Imm} = (K_{m} +) * \left(1 - \frac{\left(CIN^{a}_{fp}\right)}{\left(CIN^{a} - LIC^{a}_{ord)}\right.}\right) * \left(CIN^{a} - LIC^{a}_{ord}\right)$$

that in the case of the simulation object, because of the absence of assets in progress (LIC_{ord}) and capital invested covered by grants (CIN^{a}_{fp}), simplifies to:

$$OF^{a}_{Imm} = (K_{m} +) * (CIN^{a})$$

where

$$K_m = \left(r_r^{real} + WRP\right) * \frac{1}{\left(1 + \frac{CS}{CnS}\right)} + K_d^{real} * (1 - t_c) * \frac{CS/CnS}{\left(1 + \frac{CS}{CnS}\right)}$$

$$= *ERP * \frac{1}{\left(1 + \frac{CS}{CnS}\right)}$$

The parameters take the values outlined in Table 5.

Table 5
Financial cost - Parameter values

Parameter	Value
CS/CnS	1.00%
risk free rate	0.50%
Kd	2.77%
WRP	1.70%
β levered	0.80%
ERP	4.00%
Rpi	1.70%
Tc	0.24%
T	0.319%
time lag	1.00%
Km + α + tc*Rai rate	5.33%

Tax charges were calculated on the basis of the formulas pursuant to Article 12 of the MTI 3:

$$OFisc^a = 0,240 * Rai^a$$

$$Rai^a = \left\{ \frac{\left[1 + \frac{(K_m + +1)*(1+rpi)-1}{(1-T)}\right]}{(1 + rpi)} - 1 \right\} * \left(1 - \frac{CIN_{fp}^a}{CIN^a}\right) * CIN^a$$

that in the case of the simulation in question, because of the absence of invested capital covered by non-refundable contributions (CIN_{fp}^a), simplifies to:

$$Rai^a = \left\{ \frac{\left[1 + \frac{(K_m + +1)*(1+rpi)-1}{(1-T)}\right]}{(1 + rpi)} - 1 \right\} * CIN^a$$

Parameters take values outlined in Table 6.

Table 6
Taxes cost - Parameter values

Parameter	Value
Rpi	1.70%
T	0,319

The component **Rc** was generated with reference only to the adjustment of the margin on activities b2, considering the following revenue and cost items:

- SMART Products Benefits (€/Y)—Revenues
- SMART Products Benefits (€/Y)—Costs

The component Rc was calculated on the basis of the formula referred to in Article 27 of the MTI3:

$$Rc_{Attività\ b}^a = \%b * \left(R_{b1}^{a-2} - C_{b1}^{a-2}\right) + [\%b * (1 +_b)] * \left(R_{b2}^{a-2} - C_{b2}^{a-2}\right)$$

where:

- R_{b1}^{a-2} e C_{b1}^{a-2} are, respectively, the revenues and costs of other water activities, other than those relating to energy and environmental sustainability objectives, as shown in the financial statements of the year ($a-$ 2);
- R_{b2}^{a-2} e C_{b2}^{a-2} are, respectively, the revenues and costs of other water activities relating to energy and environmental sustainability objectives, as shown in the financial statements of the year ($a-$ 2):
- $\%b$ = 0,5;
- γb = 0,5; for which the explicit formula becomes:

$$Rc^{a}_{Attività\ b} = 0,5 * \left(R^{a-2}_{b1} - C^{a-2}_{b1}\right) + [0,5 * (1 + 0,5)] * \left(R^{a-2}_{b2} - C^{a-2}_{b2}\right)$$

$$Rc^{a}_{Attività\ b} = 0,5 * \left(R^{a-2}_{b1} - C^{a-2}_{b1}\right) + [0,75] * \left(R^{a-2}_{b2} - C^{a-2}_{b2}\right)$$

in the case of simulation, only b2 activities are present. Therefore:

$$Rc^{a}_{Attività\ b} = [0,75] * \left(R^{a-2}_{b2} - C^{a-2}_{b2}\right)$$

The residual value, valued equal to the amount of the Capex of the last two years (The cost of capital over the last two years finds financial manifestation in the twenty-first and 20-s year for the two-year time lag on investments) and the adjustments of the Rc component of the last two years, instead of being highlighted separately as required by MTI3, is placed within the simplified simulation scheme, in the items Capex and Rc.

The next Tables (7–26) show, the tariff plan of the individual Smartech, that is the simulation of the tariff components on 20 years. The Capex and Rc components start from 2022, by the investments are recognized with a time lag of two years (Article 11.6). Also sharing on the margin of the activities b "Other water activities" is recognized in tariff two years later (Article 27, MTI3).

For each plant, the related tariff plan was calculated without and with the adoption of SMARTechs. The economic effect on the IWS company was identified by comparing the results of the tariff simulation in the two situations.

Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.jup.2023.101593.

References

Abu-Ghunmi, D., Abu-Ghunmi, L., Kayal, B., Bino, A., 2016. Circular economy and the opportunity cost of not "closing the loop" of water industry: the case of Jordan. J. Clean. Prod. 131, 228–236. https://doi.org/10.1016/j.jclepro.2016.05.043.

Akyol, Ç., Foglia, A., Ozbayram, E.G., Frison, N., Katsou, E., Eusebi, A.L., Fatone, F., 2020. Validated innovative approaches for energy-efficient resource recovery and re-use from municipal wastewater: from anaerobic treatment systems to a biorefinery concept. Crit. Rev. Environ. Sci. Technol. 50, 869–902. https://doi.org/10.1080/10643389.2019.1634456.

AquaMinerals, 2018. Annual Report 2018. https://aquaminerals.com/wp-content/uploads/2019/06/Jaarbericht_AquaMinerals_18_EN.pdf.

ARERA Resolution n. 580/2019/R/IDR.

ARERA Resolution n. 585/2012/R/IDR.

ARERA Resolution n. 639/2021/R/IDR.

ARERA Resolution n. 643/2013/R/IDR.

ARERA Resolution n. 664/2015/R/IDR.

ARERA DCO 402/2019/R/IDR https://www.arera.it/it/docs/19/402-19.htm.

Arera Determination, n., 2020. 1/2020 – DSID of 29 June.

Barbosa, A., Brusca, I., 2015. Governance structures and their impact on tariff levels of Brazilian water and sanitation corporations. Util. Pol. 34, 94–105. https://doi.org/10.1016/j.jup.2015.02.002.

Barraqué, B., 2020. Full cost recovery of water services and the 3 T's of OECD. Util. Pol. 62, 100981 https://doi.org/10.1016/j.jup.2019.100981.

Bolognesi, T., Pinto, F.S., Farrelly, M. (Eds.), 2022. Routledge Handbook of Urban Water Governance. Taylor & Francis.

Bowhill, B., 2008. Business Planning and Control: Integrating Accounting, Strategy, and People. John Wiley & Sons.

Capodaglio, A.G., 2017. Integrated, decentralized wastewater management for resource recovery in rural and peri-urban areas. Resources 6 (2), 22. https://doi.org/10.3390/resources6020022.

Carrozza, C., 2011. Italian water services reform from 1994 to 2008: decisional rounds and local modes of governance. Water Pol. 13 (6), 751–768. https://doi.org/10.2166/wp.2011.030.

Choudhary, D., Qaiser, F.H., Choudhary, A., Fernandes, K., 2022. A model for managing returns in a circular economy context: a case study from the Indian electronics industry. Int. J. Prod. Econ. 249, 108505 https://doi.org/10.1016/j.ijpe.2022.108505.

Christodoulou, A., Stamatelatou, K., 2016. Overview of legislation on sewage sludge management in developed countries worldwide. Water Sci. Technol. 73 (3), 453–462. https://doi.org/10.2166/wst.2015.521.

Commission of European Communities, 2014. Toward a Circular Economy: A Zero Waste Program for Europe. COM. No. 398).

Commission of European Communities, 2015. Closing the Loop – an EU Action Plan for the Circular Economy. COM No. . 614).

Cooper, B., Crase, L., 2016. Governing water service provision: lessons from Australia. Util. Pol. 43, 42–47. https://doi.org/10.1016/j.jup.2016.06.005.

Danesi, L., Passarelli, M., Peruzzi, P., 2007. Water services reform in Italy: its impacts on regulation, investment and affordability. Water Pol. 9 (1), 33–54. https://doi.org/10.2166/wp.2006.059.

De Angelis, R., 2020. Circular economy: laying the foundations for conceptual and theoretical development in management studies. Manag. Decis. 59 (6), 1209–1227. https://doi.org/10.1108/MD-05-2019-0587.

Diaz-Elsayed, N., Rezaei, N., Ndiaye, A., Zhang, Q., 2020. Trends in the environmental and economic sustainability of wastewater-based resource recovery: a review. J. Clean. Prod. 265, 121598 https://doi.org/10.1016/j.jclepro.2020.121598.

Directive 2000/60/EC. *Establishing a Framework for Community Action in the Field of Water Policy* (EU Water Framework Directive – WFD). European Parliament and Council.

Directive 2184/20/EC. *On The Quality of Water Intended for Human Consumption* (Drinking Water Directive). European Parliament and Council.

Directive 91/271/EEC. Concerning Urban Waste Water Treatment. European Parliament and Council.

Eggimann, S., Mutzner, L., Wani, O., Schneider, M.Y., Spuhler, D., Moy de Vitry, M., Beutler, P., Maurer, M., 2017. The potential of knowing more: a review of data-driven urban water management. Environ. Sci. Technol. 51 (5), 2538–2553. https://doi.org/10.1021/acs.est.6b04267.

European Environmental Agency, 2020. Urban Wastewater Treatment in Europe. https://www.eea.europa.eu/data-and-maps/indicators/urban-waste-water-treatment/urban-waste-water-treatment-assessment-5.

European Federation of National Associations of Water Services, 2018. The Governance of Water Services in Europe. www.eureau.org/resources/news/1-the-governance-of-water-services-in-europe.

Fatone, F., Loederer, C., Wintgens, T., Rodríguez, J.A.A., Hospido, A., 2017. 6–9 September). *Municipal Wastewater Treatment to Deliver Circular Economy in the Water Sector*. 9th International Conference on Environmental Engineering and Management, Bologna, Italy. https://www.smart-plant.eu/index.php/circular-economy.

Flores, C.C., Bressers, H., Gutierrez, C., de Boer, C., 2018. Towards circular economy – a wastewater treatment perspective, the Presa Guadalupe case. Management Research Review 41 (5), 554–571. https://doi.org/10.1108/MRR-02-2018-0056.

Foglia, A., Bruni, C., Cipolletta, G., Eusebi, A.L., Frison, N., Katsou, E., Akyol, C., Fatone, F., 2021. Assessing socio-economic value of innovative materials recovery solutions validated in existing wastewater treatment plants. J. Clean. Prod., 129048 https://doi.org/10.1016/j.jclepro.2021.129048.

Gallo, A., 2014. A refresher on net present value. Harv. Bus. Rev. 19. https://hbr.org/2014/11/a-refresher-on-net-present-value.

Ghafourian, M., Nika, C.E., Mousavi, A., Mino, E., Al-Salehi, M., Katsou, E., 2022. Economic impact assessment indicators of circular economy in a decentralised circular water system – case of eco-touristic facility. Sci. Total Environ. 822, 153602 https://doi.org/10.1016/j.scitotenv.2022.153602.

Gherghel, A., Teodosiu, C., De Gisi, S., 2019. A review on wastewater sludge valorisation and its challenges in the context of circular economy. J. Clean. Prod. 228, 244–263. https://doi.org/10.1016/j.jclepro.2019.04.240.

Ghisellini, P., Cialani, C., Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. 114, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007.

Grievson, O., Holloway, T., Johnson, B., 2022. A Strategic Digital Transformation for the Water Industry. IWA Publishing, London.

Guerra-Rodríguez, S., Oulego, P., Rodríguez, E., Singh, D.N., Rodríguez-Chueca, J., 2020. Towards the implementation of circular economy in the wastewater sector: challenges and opportunities. Water 12 (5), 1431.

Guerrini, A., Manca, J., 2020. Regulatory interventions to sustain circular economy in the water sector: insights from the Italian Regulatory Authority (ARERA). H2Open Journal 3 (1), 499–518. https://doi.org/10.2166/h2oj.2020.121.

Guerrini, A., Romano, G., 2013. The process of tariff setting in an unstable legal framework: an Italian case study. Util. Pol. 24, 78–85. https://doi.org/10.1016/j.jup.2012.10.002.

Guerrini, A., Romano, G., Campedelli, B., 2011. Factors affecting the performance of water utility companies. Int. J. Public Sect. Manag. 24 (6), 543–566. https://doi.org/10.1108/09513551111163657.

Hazen, B.T., Russo, I., Confente, I., Pellathy, D., 2020. Supply chain management for circular economy: conceptual framework and research agenda. Int. J. Logist. Manag. 32 (2), 510–537. https://doi.org/10.1108/IJLM-12-2019-0332.

International Water Association, 2016. Water Utility Pathways in a Circular Economy. https://www.iwa-network.org/wp-content/uploads/2016/07/IWA_Circular_Economy_screen.pdf.
Jokar, D., Khakzand, M., Faizi, M., 2021. The application of low impact development approaches toward achieving circularity in the water sector: a case study from Soltan Abad, Shiraz, Iran. J. Clean. Prod. 320, 128712 https://doi.org/10.1016/j.jclepro.2021.128712.
Law No. 133 of 2008.
Law No. 36 of 1994.
Lazurko, A., 2018. *Assessing The Value of Resource Recovery and Reuse: Social, Environmental and Economic Costs and Benefits for Value Creation and Human Well-Being* (Resource Recovery and Reuse Series 13, No. H049081). International Water Management Institute. https://doi.org/10.5337/2018.229.
Lieder, M., Rashid, A., 2016. Towards circular economy implementation: a comprehensive review in context of manufacturing industry. J. Clean. Prod. 115, 36–51. https://doi.org/10.1016/j.jclepro.2015.12.042.
Liu, Q., Yang, L., Yang, M., 2021. Digitalisation for water sustainability: barriers to implementing circular economy in smart water management. Sustainability 13 (21), 11868. https://doi.org/10.3390/su132111868.
Magni, C.A., 2010. Average internal rate of return and investment decisions: a new perspective. Eng. Econ. 55 (2), 150–180. https://doi.org/10.1080/00137911003791856.
Marques, R., 2010. Regulation of Water and Wastewater Services: an International Comparison. IWA Publishing. https://doi.org/10.2166/9781780401492.
Marques, R.C., Miranda, J., 2020. Sustainable tariffs for water and wastewater services. Util. Pol. 64, 101054 https://doi.org/10.1016/j.jup.2020.101054.
Massarutto, A., 2020. Servant of too many masters: residential water pricing and the challenge of sustainability. Util. Pol. 63, 101018 https://doi.org/10.1016/j.jup.2020.101018.
Massoud, M.A., Tarhini, A., Nasr, J.A., 2009. Decentralized approaches to wastewater treatment and management: applicability in developing countries. J. Environ. Manag. 90 (1), 652–659. https://doi.org/10.1016/j.jenvman.2008.07.001.
Mauchauffee, S., Denieul, M.P., Coste, M., 2012. Industrial wastewater reuse: closure of water cycle in the main water consuming industries – the example of paper mills. Environ. Technol. 33 (19), 2257–2262. https://doi.org/10.1080/09593330.2012.728734.
Mbavarira, T.M., Grimm, C., 2021. A systemic view on circular economy in the water industry: learnings from a Belgian and Dutch case. Sustainability 13 (6), 3313. https://doi.org/10.3390/su13063313.
Ministerial Decree 01/08/1996.
Molinos-Senante, M., Donoso, G., 2016. Water scarcity and affordability in urban water pricing: a case study of Chile. Util. Pol. 43, 107–116. https://doi.org/10.1016/j.jup.2016.04.014.
Neczaj, E., Grosser, A., 2018. Circular economy in wastewater treatment plant – challenges and barriers. Proceedings 2 (11), 614. https://doi.org/10.3390/proceedings2110614.
Nika, C.E., Gusmaroli, L., Ghafourian, M., Atanasova, N., Buttiglieri, G., Katsou, E., 2020. Nature-based solutions as enablers of circularity in water systems: a review on assessment methodologies, tools and indicators. Water Res. 183, 115988 https://doi.org/10.1016/j.watres.2020.115988.
Ofwat, 2021. Bioresources Market. https://www.ofwat.gov.uk/regulated-companies/markets/bioresources-market.
Pinto, F.S., Marques, R.C., 2015. Tariff structures for water and sanitation urban households: a primer. Water Pol. 17, 1108–1126. https://doi.org/10.2166/wp.2015.188.
Reynaud, A., Romano, G., 2018. Advances in the economic analysis of residential water use: an introduction. Water 10, 1162–1171. https://doi.org/10.3390/w10091162.
Romano, G., Guerrini, A., Campedelli, B., 2015. The new Italian water tariff method: a launching point for novel infrastructures or a backward step? Util. Pol. 34, 45–53. https://doi.org/10.1016/j.jup.2015.01.003.
Romano, G., Guerrini, A., Senoner, T., 2020. Establishing a new water tariff method that complies with European principles and respects statutory autonomy: the case of South Tyrol. Util. Pol. 64, 101050 https://doi.org/10.1016/j.jup.2020.101050.
Şahin, N.İ., Manioğlu, G., 2019. Water conservation through rainwater harvesting using different building forms in different climatic regions. Sustain. Cities Soc. 44, 367–377. https://doi.org/10.1016/j.scs.2018.10.010.
Smart-Plant, 2020. D4.4 Environmental Impact Report, Incl. LCA (Life Cycle Assessment). https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5cfaec6f1&appId=PPGMS.
Smith, H.M., Brouwer, S., Jeffrey, P., Frijns, J., 2018. Public responses to water reuse – understanding the evidence. J. Environ. Manag. 207, 43–50. https://doi.org/10.1016/j.jenvman.2017.11.021.
Smol, M., Kulczycka, J., Avdiushchenko, A., 2017. Circular economy indicators in relation to eco-innovation in European regions. Clean Technol. Environ. Policy 19 (3), 669–678. https://doi.org/10.1007/s10098-016-1323-8.
Smol, M., Adam, C., Preisner, M., 2020. Circular economy model framework in the European water and wastewater sector. J. Mater. Cycles Waste Manag. 22, 1–16. https://doi.org/10.1007/s10163-019-00960-z.
Voulvoulis, N., 2018. Water reuse from a circular economy perspective and potential risks from an unregulated approach. Current Opinion in Environmental Science and Health 2, 32–45. https://doi.org/10.1016/j.coesh.2018.01.005.
WAREG, 2019. Tariff Regulatory Frameworks in WAREG Member Countries. https://www.wareg.org.
Weingartner, H.M., 1969. Some new views on the payback period and capital budgeting decisions. Manag. Sci. 15 (12), B–594. https://doi.org/10.1287/mnsc.15.12.B594.