Water Reuse and Water Utilities: An Economic Framework

Enrico Cagno
Department of Management Engineering
Politecnico di Milano, Milan, Italy
e-mail: enrico.cagno@polimi.it

Paola Garrone, Marta Negri, Andrea M. Rizzuni*
Department of Management Engineering
Politecnico di Milano, Milan, Italy
e-mail: paola.garrone@polimi.it
marta.negri@polimi.it
andreamatteo.rizzuni@polimi.it

ABSTRACT

Concerns for water scarcity lead academics, operators and policymakers to consider the option of water reuse. In this paper, a framework modelling the water reuse system is developed along three dimensions: reuse loop topology (reuse water source and destination), effluent quality (basic reclamation or potabilization), reuse technology owner (investor). Since the attitude of water utilities crucially affects the development of water reuse systems, an analytical model of the utility's margin variation is then built, based on data from a water utility in Southern Italy, an area subject to frequent water shortages. Simulations show that under most scenarios water reuse technologies are not economically sustainable. Despite cost savings, adoption is made unprofitable by urban water revenues cannibalization, even before considering the capital and operating costs of reuse technologies. However, geographical dispersion of users and selected policy measures can enhance the economics of water reuse schemes.

KEYWORDS

Water reuse; water utilities; economic model; water reuse economics; price regulation; sustainability.

1. INTRODUCTION

Water scarcity is already today a major problem for many communities. Demand growth and climate changes are likely to furtherly exacerbate the issue [1]. The reuse of treated wastewater could represent a valuable option to reduce the pressure on fresh water consumption [2]. Both non-potable (i.e. irrigation, industrial processes, city and ecological services) and potable applications are feasible, although the latter are more controversial due to health and social acceptance concerns [3] [4]. If correctly implemented, water reuse could foster energy and water conservation [5], by-products recovery [6] and economic savings [7].

In spite of the recognized benefits of reusing wastewater, major barriers still hinder the adoption of reuse practices. Among others, high initial investment in the absence of subsidies [8], uncertain acceptability of reusing wastewater [2], coordination costs among utilities (i.e. those providing drinkable water and those providing the wastewater treatment service, if separate) [9], hamper the development of reuse systems. It is therefore necessary to understand conditions under which water reuse schemes become economically sustainable.

* Corresponding author

In this context, water utilities, namely the urban water operators[1], are a key stakeholder in the take-off of water reuse projects. First, they operate wastewater treatment plants that are a major supply source for reuse water. Second, utilities may resist or foster the deployment of reuse systems, because the consumption of reuse water has a deep impact on their revenues and costs [10].
This study aims at filling two main research gaps found in the literature [11,12], by shedding light on the economic and operational drivers that foster the adoption of reuse technologies by water utilities. In greater detail, it identifies the main conditions that make the adoption of new technologies by a water utility economically sustainable, taking utilities as a pivotal actor in the development and spreading of water reuse technologies and practices.
In particular, the paper addresses the following research questions:

- RQ1: *what is the role played by water reuse schemes in the urban water system?*
- RQ2: *which conditions make reuse schemes economically sustainable for the water utility?*

In so doing, our study yields two main results: 1) a framework that clarifies the relationships between the water reuse system, the utility and its users; 2) a preliminary economic model of the response of the utility's margin to the adoption of reuse technologies, namely to the shift of consumption from urban to reuse water. The model analysis and simulations are developed to pinpoint the main context characteristics that allow to analyze the economic sustainability of an investment in reuse technologies. Furthermore, hints on how the main price regulation measures may enhance water reuse technologies adoption are provided.
This study contributes to the ongoing dialogue on water reuse in management and engineering academic literature, in particular deepening an underexplored issue, i.e. economic sustainability for water utilities of the adoption of water reuse technologies. Besides, it could prove useful to utility managers, as they will have a better understanding of the economic implications of water reuse, and to policy makers who strive to smooth the economic barriers hindering water reuse.

The remainder of the paper is structured as follows. In Section 2, the methods are outlined. In Section 3, the conceptual framework linking water utilities to the water system and its users is developed. In Section 4, the context, main assumptions and development of the model of the utility's margin change following the adoption of water reuse technologies are presented. In Section 5, main results are exposed. Section 6 provides a discussion of the results and conclusions.

2. METHODS

This work is part of a wider European Commission's research project on water reuse. This project at large aims at showing the potential of reused water as an unconventional water source to alleviate the pressure on freshwater withdrawal, and show under which conditions such schemes could result viable. The project focuses on low-cost, modular technologies, which could enable small firms and communities to implement such solutions. These technologies will be developed and scaled up, to be then applied to four demo sites, i.e., water utilities located in Italy, Israel, Spain and Croatia.

As per this study's objectives, a first literature review allowed to build the conceptual framework presented in Section 3. A second review has been performed to retrieve the most important contributions on urban water economics, mainly referring to financial statements from Italian water utilities and regulatory authorities' documents, so to build the model presented in Section 4.

The insights gathered from the literature review have been complemented with semi-structured interviews [13,14] performed with experts of the water sector in one of the four demo sites identified

[1] In this paper, we refer to the conventional (i.e., not reused) water resource provided by the water utility as "urban water"

in the project, namely the Italian one. This demo site was selected as a representative case, and the experts as knowledgeable of the sector [15]. Interviews have been conducted to gather a first feedback on results, to improve their robustness and gain more insights on the topic of water reuse [16,17]. In particular, interviews were carried out with a responsible of the technical operations of the water utility and with an expert for the regulatory department. Secondary sources of data were used for triangulation, to corroborate the insights provided by the interviewees, so to reduce personal bias [18,19]. These included the utility's financial reports, articles and studies available online.

The selected water utility operates in Southern Italy and manages a large urban water distribution and wastewater collection and treatment system, with a distribution network of some thousands of kilometres and sewage network of several dozens of wastewater treatment plants. Conventional water sources, mainly rivers and artificial and natural reservoirs, are increasingly exposed to stress. The European Environment Agency reports that the population residing in the Southern Europe countries is increasingly experiencing water stress conditions caused by growing consumption for agriculture and cooling electricity plants and, on the supply side, climate changes [20]. Rainfall is quite scarce in the region, with a mean annual value of rainfall below 500 mm [21]. Water shortage episodes are occurring across a few locations in summer, where demand increases owing to the presence of heavy tourism. In this scenario, it could be particularly interesting to exploit water reuse as a means to reduce pressures on freshwater resource.

3. CONCEPTUAL FRAMEWORK

The adoption of a reuse technology is economically sustainable when the variation in utility's income that is caused by the demand shift matches the costs of reuse technologies, also considering possible support policies (e.g., subsidies, tariff incentives and other economic measures) [10], or when it allows to generate further revenues coming from a previously unsatisfied demand in situations of scarcity [22]. Whether reuse technologies are operated by urban water utilities or users, reuse water partially replaces urban water demand [23]. Alternatively, in cases of rationed demand owing to low supply (such as drought areas or periods), reuse technologies may generate an additional source of water and allow the utility to serve a previously unsatisfied demand portion [24].
It is therefore necessary to understand the different possible deployment patterns, as they have different implications for utility's revenues and costs, and explain the heterogeneity of pricing and cost allocation approaches to reuse water across regulated utilities [25].

The deployment patterns are governed by three dimensions:

1. Ownership of reuse technology (who bears the investment). The reuse technology can be installed by the utility [26] or the end user [27]. In the first case, the technology can be installed either at the utility's premises or at the end-user's premises, which are also called centralized and decentralized solutions, respectively [28]. Siting the technology directly at the users' premises may have some advantages, such as the fostering of reuse schemes close to the point of generation, lower investment, lower costs of connections, although lower economies of scale are to be expected [29].
2. The reuse loop topology (from the treated wastewater source to the reclaimed water end use). The wastewater can be sourced either by the utility or the user, with implications for the feasibility of the solution. If wastewater is sourced by the utility and the technology is located at the user's premises, or the wastewater is sourced by the end-user but the technology is located at the utility's premises (or any other combined configuration), a dedicated infrastructure will have to be built to transport water [2,9,29]. Having wastewater sourced by the user opens interesting avenues for proactively managing water demand, where the utility

may be incentivized to invest to reduce the water demand in locations with particular scarcity, or where the cost for delivering the water is higher than the revenues gained [30].
3. The quality of the effluent (basic reclamation or potable-like reclamation). The effluent can be treated at various levels of quality, and it should comply with strict standards in case of potability [8].

The deployment patterns, based on the aforementioned dimensions, are summarized in Table 1.

Table 1. Conceptual framework of deployment patterns

		Reuse loop topology			
		Wastewater sourced by the utility		***Wastewater sourced by the user***	
		Basic reclamation	***Potabilization***	***Basic reclamation***	***Potabilization***
Effluent quality		*Outer loop - Reuse water distributed to users*	*Inner loop - Reuse water supplied to the urban water distribution network*	*Inner loop - Reuse water recirculated into the user network*	*Outer loop - Reuse water sourced into the urban water distribution network*
Reuse technology owner	***Utility***	Pattern 1.1a Reuse technology located: I. at the utility premises (upstream of reuse water distribution network) II. at the user premises (downstream of wastewater delivery network)	Pattern 1.1b Reuse technology located at the utility premises	Pattern 1.2a Reuse technology located at the user premises	Pattern 1.2b Reuse technology located at the nearest urban water distribution network
	User	Pattern 2.1 Reuse technology located at the user premises		Pattern 2.2 Technology located at the user premises	

4. MODEL PRESENTATION

In Italy, obligations on reuse water were defined in 2003 (D.M. 12 June 2003, n. 185). Reuse water has to meet quality standards that are stricter than standards for urban wastewater released in water bodies by treatment plants (Annex 1 of D.M 12 June 2003, n. 185 vs. Annex 5 of D.Lgs. 11 May 1999, n. 152). Treated urban wastewater becomes reuse water when it undergoes further treatment ("reclamation").

Main model assumptions. First, at this stage of the research only industrial users are assumed to consume reuse water. Indeed, non-industrial users are subject to stricter regulation (D.M. 12 June 2003, n. 185; EU Regulation 2020/741 of 25 May 2020 on minimum requirements for water reuse). Italian obligations on reuse water do not admit residents as users, and forbid reusing water in irrigation, if it comes in contact with raw crops and public green areas (D.M. Ambiente 12 June 2003, n. 185, Articles 3 and 14). Furthermore, industrial users of urban water are relatively few but have comparatively higher consumption volumes.
Second, spread of reuse water technologies is assumed to be gradual, i.e., a short-medium time horizon is assumed. In the long run, the utility could redesign urban water networks following the adoption of reuse technologies because reuse water may substitute for freshwater resources. Nevertheless, in the initial phase of diffusion of reuse schemes, it seems unlikely that the utility carries out any expansion investment or divestment in urban water and wastewater networks, also because reuse water is assumed, in some cases, to integrate (and not replace) existing freshwater resources, in

areas and periods of particular scarcity. The only observed investment is the deployment of reuse technologies and related systems (e.g., reuse water distribution network).
Thirdly, the cost and revenue functions of urban water and reuse water are assumed to be linear and mutually separable. The assumption of separability captures the idea that the operations of the two utility's divisions do not have important scope economies. For the sake of simplicity, neither taxes nor interests are considered.
Furthermore, in the current phase of research only revenues and costs attributable to the urban water division of the utility will be modelled. A comprehensive evaluation of the economic sustainability of reuse technologies will be obtained by comparing the urban water margins to revenues and costs coming from reuse activities. Additionally, only differential components of the cost and revenue functions are modelled, i.e., variable costs and revenues. Given the lack of expansion investment or divestment it can be assumed that fixed investment and operating costs after reuse technology adoption are the same as before adoption, as well as fixed revenues (access fees).
Finally, in this stage of the research the model assumes demand to be completely rigid, and the replacement degree of urban water to be exogenously given. The assumption of rigid demand is considered a reasonable first approximation as water demand has been consistently estimated to be rigid, especially in conditions of scarcity [31]. Furthermore, considered the nature of the tariff for urban water (regulated market through a revenue cap scheme in the Italian context), it is reasonable to assume that a lower demand of urban water does not lead to a decrease of the unitary tariff in the short run.

<u>Model setting</u>. *Opex* (Operating Expenditures) represent the variable portion of operating costs to provide urban water and collect and treat wastewater [€/year]. It mainly includes labour, materials and external services, environmental and resource costs (wastewater treatment, potabilization, losses telemonitoring and control), energy and wholesale water costs. q^U [m^3/user-year] represents the average yearly consumption of urban water from industrial users, q^R [m^3/user-year] the average yearly consumption of reuse water from industrial users, and *N* [users] the number of industrial users. The average (unitary) value *AOpex* of variable operating costs [€/m^3] may be found by dividing *Opex* by the total yearly quantity provided to industrial users. The yearly total costs (*TC*) incurred are the *Opex* multiplied by the yearly level of consumption from industrial users. If water is reused, *Opex* are reduced, i.e. the decreased consumption of urban water services reduces the sales of urban water services to users, and consequentially it reduces the variable costs for operating urban water services.

$$AOpex = \frac{Opex}{q^U \cdot N} \tag{1}$$

$$TC^{noreuse} = AOpex \cdot q^U_{noreuse} \cdot N \tag{2}$$

$$TC^{reuse} = AOpex \cdot q^U_{reuse} \cdot N \tag{3}$$

$$\text{Where } \; q^U_{reuse} = q^U_{noreuse} - q^R \tag{4}$$

Given the assumption of linearity, the variation in costs in the presence of reuse can be formulated as follows:

$$\Delta TC = TC^{reuse} - TC^{noreuse} = -(AOpex) \cdot q^R \cdot N \tag{5}$$

R represents the yearly variable revenues obtained by the urban water division of the utility [€/year]. The tariff is modelled to be made up by two block rates for the unitary rate for water distribution (D_0 and D_1) [€/m^3] separated by the upper bound of the lower block (B) [m^3/user-year], and a homogeneous unitary rate for wastewater collection and wastewater treatment (CT) [€/m^3]. The decreased consumption of urban water services reduces the sales of urban water services to users, and consequentially it reduces the revenues for urban water services.

$$R^{noreuse} = D_0 \cdot min\{q^U_{noreuse}; B\} \cdot N + D_1 \cdot max\{q^U_{noreuse} - B; 0\} \cdot N \ + CT \cdot q^U_{noreuse} \cdot N \tag{6}$$

$$R^{reuse} = D_0 \cdot min\{q^U_{reuse}; B\} \cdot N + D_1 \cdot max\{q^U_{reuse} - B; 0\} \cdot N + CT \cdot q^U_{reuse} \cdot N \tag{7}$$

The margin is defined as the difference between revenues R and total costs TC.

$$M^{noreuse} = R^{noreuse} - \ TC^{noreuse} \tag{8}$$

$$M^{reuse} = R^{reuse} - \ TC^{reuse} \tag{9}$$

$$\Delta M = M^{reuse} - \ M^{noreuse} \tag{10}$$

$$\text{if } q^U_{reuse} > B \text{ then } \Delta M = (AOpex - CT - D_1) \cdot q^R \cdot N \tag{11}$$

$$\text{if } q^U_{noreuse} > B \text{ and } q^U_{reuse} \leq B \text{ then } \Delta M = (AOpex - CT) \cdot q^R \cdot N - D_0 \cdot (B - q^U_{reuse}) \cdot N - D_1 \cdot (q^U_{noreuse} - B) \cdot N \tag{12}$$

$$\text{if } q^U_{noreuse} \leq B \text{ then } \Delta M = (AOpex - CT - D_0) \cdot q^R \cdot N \tag{13}$$

where total water consumption is exogenously given and equal to $q^U_{noreuse} = q^U_{reuse} + \ q^R$.

To understand the impact of the adoption of water reuse technologies, an exogenous demand shift from urban to reuse water is considered, given a rigid demand function. In Table 2, the general characteristics of the simulated utility are presented. Values are partially calibrated taking inspiration from the studied utility.

Table 2. Characteristics of the simulated utility

Characteristic	**Parameter**	**Value**	**Source**
Number of industrial users	N	1,000 [users]	Hypothesis
Average total (urban + reuse) consumption of water by an industrial user	q	3,000 [m^3/user-year]	Interviews
Average unitary operating cost	AOpex	1.18 [€/m^3]	Utility's 2019 financial statements
Average unitary energy cost	EnCost	0.25 [€/m^3]	Utility's 2019 financial statements
Unitary rate (variable tariff) - water distribution	D	Base block: 1.29 [euro/m^3], D_0 First block: 1.71 [euro/m^3], D_1	Authority's 2020 tariff plan
Unitary rate (variable tariff) - wastewater collection and treatment	CT	0.49 [euro/m^3]	Authority's 2020 tariff plan
Base block upper bound	B	400 [m^3/user-year]	Authority's 2020 tariff plan (rounded)

5. SIMULATIONS AND RESULTS

5.1. The simulations

In the baseline scenario users satisfy their water demand through urban water, and are homogeneously located at an average distance from the source. Such distance is the one which makes users have an energy cost to be served equal to the average energy cost per m^3, as presented in Table 2.

Table 3 presents the characteristics of the baseline scenario.

Table 3. The baseline scenario

Variable	Parameter	Value
Number of industrial users who do not reuse	N^U	1,000 [users]
Number of industrial users who adopt reuse	N^R	0 [users]
Average consumption of reuse water by an industrial user	q^R	0 [m^3/user-year]
Location of users adopting reuse	L^R	Uniformly set at L^{MEAN} (distance from sources that makes the energy cost per cubic meter equal to the mean energy cost observed)

The dependent variable is the variation in margin *(ΔM)* and the simulated parameters are two.
1) Reuse diffusion (for the “diffusion” simulation): the degree to which reuse has diffused is captured by the percentage of adopters (N^R/N), ranging from 10% to 100%, holding constant the relative distance of users from the barycenter of the network.
2) Location of users (for the “location” simulation): the distance of users from the barycenter of the network is modelled relatively to the average distance (L^R/ L^{MEAN}), ranging from 1 to 10, holding constant the diffusion degree. Far users have a relatively higher energy cost to be served proportional to their distance.
In both simulations, water reuse demand (q^R) for each industrial user is treated as an exogenous independent variable, moving from 0 to 3,000 [m^3/year]. To measure the economic effect of reuse adoption in the utility, the variation in total margin caused by the shift to reuse water is divided by the number of users adopting reuse and by the yearly consumption of reuse water to develop two synthetic indicators, namely the variation in margin per user ΔMU [€/user-year] and in margin per reuse volume ΔMV [€/m^3].

5.2 Results

Diffusion simulation. Users homogeneously shift their water demand from urban water to reuse water, gradually from 0 to 3,000 [m^3/year]. The impact of the variation in the operating margin for the utility is computed considering different levels of diffusion (N^R/N ranging from 10-100% of users).

Figure 1 shows that the effect of a gradual demand shift towards reuse water is a loss of revenues coming from urban water, partially balanced by a reduction of related operating variable costs. The reduction in revenues is mitigated when demand of users falls in the base block (below 400 m^3/year) and the unitary tariff becomes lower (leading to a smaller revenue loss per m^3). The overall result is a reduction (a negative variation) in the utility’s margin, proportionally larger as the diffusion of reuse becomes higher.

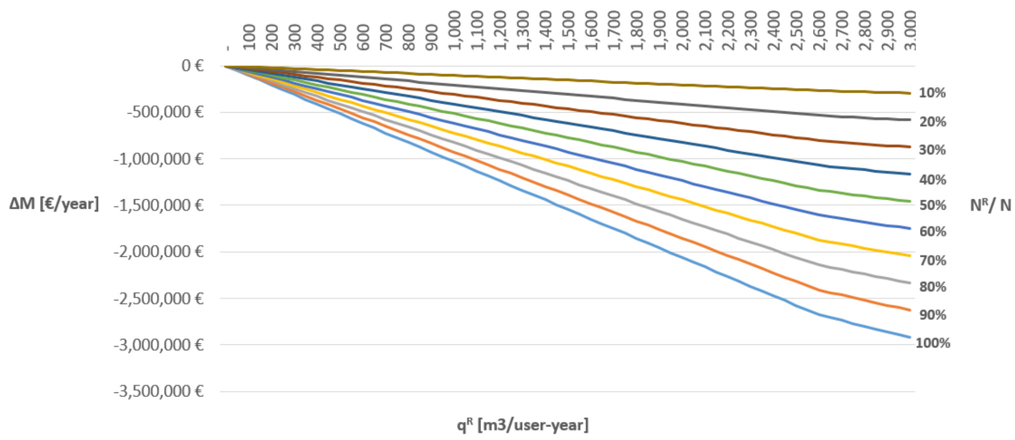

Figure 1. Change in margin due to a shift towards reuse water for different levels of adoption of reuse of homogenous industrial users

In Table 4, the variation in operating margin per user and per m^3 are reported for different levels of consumption of reuse water. The utility faces a loss of 0.97-1.03€ for each m^3 of demand shifted towards reuse water, and can lose as much as 2,919€/year for each industrial user, when it shifts completely to reuse water.

Table 4. Unitary margin variations for different levels of reuse water consumption

Reuse water consumption, q^R [m^3/user – year]	Variation in unitary margin per user, ΔMU [€/user-year]	Variation in unitary margin per reuse volume, ΔMV [€/m^3]
250	-257	-1.03
500	-515	-1.03
750	-772	-1.03
1,000	-1,029	-1.03
1,250	-1,287	-1.03
1,500	-1,544	-1.03
1,750	-1,802	-1.03
2,000	-2,059	-1.03
2,250	-2,316	-1.03
2,500	-2,574	-1.03
2,750	-2,767	-1.00
3,000	-2,919	-0.97

Location simulation. A portion of users (10%, equal to 100 users) homogeneously shift their water demand from urban water to reuse water, gradually from 0 to 3,000 [m^3/year]. The impact of the variation in the margin for the utility is computed considering different locations of users adopting reuse technologies, who progressively increase their dispersion away from the barycenter of the network (L^R/L^{MEAN} ranging from 1 to 10 times). In the simulation, the average distance from the barycenter (average energy cost) is kept constant (e.g., when the 10% of "far" users are farther away, this is compensated by the other 90% being closer to the source), so that the average energy cost for urban water remains as reported in Table 2.

Figure 2 shows the effect of a gradual shift towards reuse water is a loss of revenues coming from urban water, balanced by a reduction of related operating variable costs. The cost savings outweigh the reduction in revenues when users are very far away from the barycentre of the network and a shift to reuse water implies high savings in energy costs. Table 5 shows the positive effect on the margin for the utility in the extreme case when users are the farthest from the barycentre of the network (10 times).

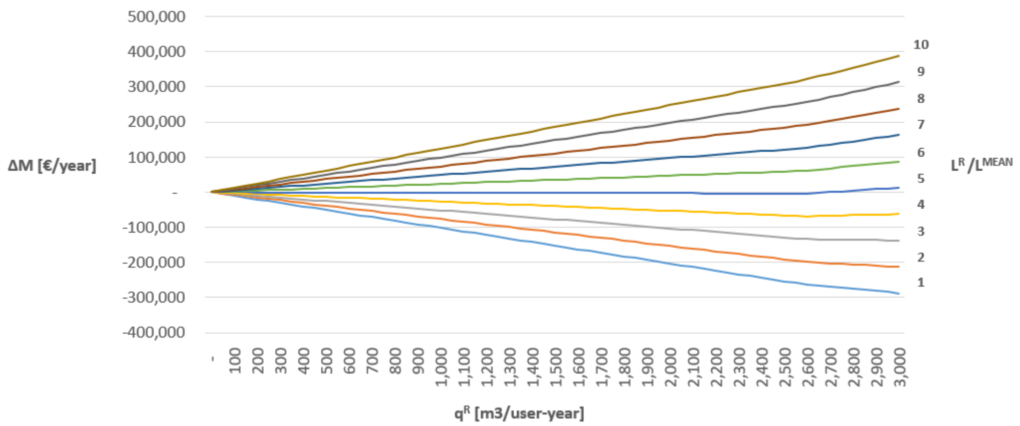

Figure 2. Change in margin due to a shift towards reuse water for users located at different distances

Table 5. Unitary margin variations for different levels of reuse water consumption for distant users (with $L^R/L^{MEAN} = 10$)

Reuse water consumption, q^R [m³/user – year]	**Variation in unitary margin per user, ΔMU [€/user-year]**	**Variation in unitary margin per reuse volume, ΔMV [€/m³]**
250	309	1.24
500	618	1.24
750	927	1.24
1,000	1,235	1.24
1,250	1,544	1.24
1,500	1,853	1.24
1,750	2,162	1.24
2,000	2,471	1.24
2,250	2,780	1.24
2,500	3,089	1.24
2,750	3,461	1.26
3,000	3,876	1.29

6. DISCUSSION AND CONCLUSIONS

The simulations presented allow to draw some conclusions. Analysing the variation in the margin of the utility generated by the adoption of water reuse technologies, it is possible to conclude that reuse adoption may prove to be unprofitable in most situations, as savings in variable operating costs are offset by a larger loss in revenues (due to the cannibalization of the demand for urban water and related revenues), even before accounting for the costs related to the deployment and operations of reuse technologies.

However, there are some specific operating conditions and user characteristics which make the investment in reuse technologies "naturally" profitable. The simulations have indeed shown how reuse from very distant or peripheral users may prove to be economically sustainable, and is therefore a desirable option for the utility. The additional margin created through relevant cost savings may serve as a preliminary benchmark for water utility managers to evaluate investment in reuse technologies according to the additional operating and capital expenditures that such investment will cause the utility to bear. Furthermore, potable reuse water may be used as a new source to fulfil the rationed demand in water shortage situations [30], therefore opening the possibility of additional revenues.

Referencing Table 1, it is possible to notice that, depending on the deployment pattern, the utility may have to bear different additional investment and operating costs through its reuse water division. For instance, in patterns where the utility is the owner of the reuse technology (1.1a, 1.1b, 1.2a, 1.2b) the utility will have to bear investment costs for installing the technology and the operational costs to perform reclamation activities, while in some patterns (1.1a I, 1.1b, 1.2b) the utility will have to bear the cost to serve the end user, which includes the building of the separate network and the operational costs to distribute. These costs will have to be compared to the variation in margin for the urban water division, and eventually additional revenues coming from appropriate policy measures.
Indeed, given the expected environmental benefits of reuse, policy measures may be an option to ease the adoption of reuse technologies by water utilities. Several price regulation measures have been proposed to cover costs related to reuse activities. Indeed, while costs to treat, reclaim and redistribute reuse water are not necessarily lower than the ones related to the urban water cycle, reuse water should be priced at a lower unitary rate than conventional urban water to incentivize consumption [32]. Price regulation of reuse water related activities– while reflecting the general principle of full cost recovery – should be integrated in the system of conventional water tariffs, considering direct and indirect costs and benefits as well as components of the system [32]. Therefore, reuse water pricing should be integrated in the system of water-related services tariffs, and indirect environmental benefits to the community should also be considered [33]. Several measures have been proposed and are being experimented, such as the possibility to sell reuse water by providing it through a separate network, with prices ranging from 33% to 63% of regular urban water [32] [34]; revenue cap increases from incentive regulation for sustainability-related activities [35]; allowance of costs to reclaim and distribute reuse water in the wastewater treatment tariff, especially where regional authorities have set high standards for wastewater treatment quality (e.g., Apulia Regional Law n.27/2008; Apulia Regional Law n.8/2012); public subsidies to cover investments related to environmental sustainability, at regional, national and European level [32] [36]; mechanisms such as the coverage of a portion of reuse costs through local taxation (i.e., municipal charges) [32].

To conclude, the adoption of reuse water systems is found to lean on a mix of favourable conditions. First, a significant shift of industrial consumption from urban to reuse water should be observed. Second, adoption by peripheral users that create high energy cost for urban water distribution (e.g., dispersed rural areas or mountain areas) is also necessary. Lastly, feasibility of investment in the new water reuse technology requires the presence of appropriate policy measures (or a combination of measures).

ACKNOWLEDGMENT

This paper has been developed based on work performed for “Project Ô” (EU project 776816) projects. We acknowledge the support from the European Commission under the H2020 programme.

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