Using reclaimed water in dual pressurized water distribution networks.

Cost Analysis

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ABSTRACT

Reclaimed water can be used for non-potable applications to reduce water consumption from freshwater sources. In several regions, the full potential of reusing treated wastewater has not yet been exploited. Establishing a circular economy could promote the acceptance of reclaimed water as an alternative water supply source. This study investigates the feasibility of constructing a treatment plant to supply reclaimed water for non-potable applications using a dual water distribution network, from an engineering cost standpoint.

KEYWORDS

Reclaimed water use, circular economy, cost analysis, dual water pressurized network

1. INTRODUCTION

In 2014, the total global water consumption was 4 trillion m³ (IEAIE, 2016). This figure has further increased by around 1% in recent years (UN, 2019). Water withdrawals are expected to rise by 70% over the next 25 y due to increased food production (Alexandratos et al., 2012). Water scarcity is aggravated by population growth (from 7.7 billion people in 2017 to 9.4–10.2 billion people by 2050 (UN, 2019)), which is expected to increase by 2–3 billion people over the next 40 y (UNESCO-WWAP, 2012). Global water consumption is predicted to

increase at an identical rate until 2050 to nearly 20%–30% above the current global water consumption (Burek et al., 2016; UN, 2019).

Agriculture accounts for 70% of total water consumption (Siebert et al., 2010; Wada et al., 2012). In 2012, 79% of water in Spain was used for agriculture and the rest was used for urban consumption, which corresponds to volumes of 15833 hm³ and 4324 hm³, respectively (Olcina Cantos et al., 2018). Consequently, the reuse of water for agricultural irrigation is an urgent requirement and promises significant water savings. Several regions around the world are experiencing growing water shortages (Winpenny et al., 2010) and consequently, reclaimed water can be used for non-potable applications to reduce freshwater demands. Although reclaimed water offers enormous potential for irrigation, there are numerous concerns related to agricultural sustainability and human health (Hamilton et al., 2005). In 2006, the total amount of reused wastewater in Spain was between 368 hm³/y and 450 hm³/y (around 10.8% and 13% of the total treated wastewater, respectively) (Jodar-Abellan et al., 2019b). The “Asociación Española de Abastecimientos” (AEAS) estimated that the annual volume of reused wastewater was 268 hm³/y (AEAS, 2017) and the “Instituto Nacional de Estadística” (INE) stated that the annual volume of reused wastewater was 493 hm³/y (INE, 2018). The province of Alicante recycled about 42% of its wastewater in 2016 (59.1 hm³ out of 139.5 hm³), and discharged the remaining wastewater into the sea after purification (Jodar-Abellan et al., 2019a). Therefore, significant improvements are required to better utilise wastewater. In Alicante city, 70% of the reclaimed water was from green urban areas, a volume of 1.2 hm³ in 2018 (Olcina Cantos et al., 2018)

Recycled water is a constant and reliable water source and reduces the amount of water extracted from the environment, while reducing conveyance costs. Moreover, the treatment procedures required for non-potable water for use in urban areas are few. This water can be used by urban residents for outdoor irrigation, non-residential toilet flushing, and washing cars, houses, and decks. Other uses include industrial processes, water-based cooling in manufacturing, and dust control at construction sites.

Some researchers have analysed the limits of the water quality of reused wastewater (Müller and Cornel, 2017; Voulvoulis, 2018), the impact of the quality of the recycled water (presence of pathogens, salinity, and chemical contaminants), both on the crop itself and on the end users of the crops (Toze, 2006), and the occurrence of certain organic trace compounds such as antibiotic residues in the reclaimed water (Hong et al., 2013). Others have analysed the benefits and risks associated with reclaimed water irrigation (Chen et al., 2013; Deng et al., 2019) and surveyed the opinions of farmers (Carr et al., 2011; Petousi et al., 2015) and suburban residents (Chen et al., 2015; Ravishankar et al., 2018). The recent Regulation (EU) 2020/741 of the European Parliament and the Council of 25 May 2020 on minimum requirements for water reuse (EU, 2020) considers these quality risks, establishes water quality requirements, and recommends suitable measures for water reuse risk management plans to protect the environment and human and animal health.

Favourable pricing (compared to potable water) and public information campaigns (highlighting the environmental benefits) are market mechanisms to encourage the adoption of reclaimed water (Metcalf et al., 2007). In China, nearly one-third of reclaimed water is used for agricultural irrigation (Wang et al., 2017). Another possible application of reclaimed municipal wastewater is groundwater recharging (Asano and Cotruvo, 2004; Sheng, 2005).

Using reclaimed water involves building a secondary network (dual network) to supply non-potable water to more customers. Such systems already exist in cities such as Hong Kong, wherein a seawater system has been implemented for toilet flushing (Tang et al., 2006), Singapore (Lee and Tan, 2016), and some cities in the USA (Barker et al., 2016). Some researchers have simulated hydraulics in a freshwater pressurised network and a dual distribution system (Kandiah et al., 2016), while others have examined the energy consumption of dual potable and reclaimed water systems (Barker et al., 2016).

In previous research, the monetary aspects of wastewater recycling have been evaluated (Chhipi-Shrestha et al., 2019), including the expenditure required for pipe and pump installation, operational expenses, and environmental expenses (Kang and Lansey, 2012). Some studies have used a cost-benefit analysis (Alcon et al., 2013) that evaluates the differences between the investment costs (handled in the present time) and the future operational expenses. Proper application of wastewater reuse projects and the incorporation of external benefits can increase their feasibility (Molinos-Senante et al., 2011). The monetary usefulness of water-reuse projects must consider the economic and environmental benefits, resource availability, and the intangible benefits (environmental enhancements, community health, and groundwater recharge and pollution) (Fan et al., 2015).

Farmers usually buy reclaimed water at low prices. To motivate water utility managers to increase the adoption of reused water, the environmental costs associated with the extraction of water must be adjusted in the form of taxes, based on the volume of freshwater used instead of reclaimed water (EUR/m³). The environmental costs C_{ENV} (EUR/m³) in Europe range from 0.84 EUR/m³ to 0 EUR/m³ in Denmark and Spain, respectively (Pardo and Valdes-Abellan, 2018).

In this study we aim to establish a procedure to measure the monetary cost that must be paid by end-users when utility managers do not use recycled water. To accomplish this, a wastewater treatment system and a pressurised dual network must be built in a district metered area (DMA). The reclaimed water can be used to irrigate urban gardens to obtain water (and economic) savings in the future, which are used to determine the payback period. To further promote water saving, the environmental impact of extracting water from the natural environment is considered, and the effect of the environmental cost on the payback period is analysed. The environmental cost of water can promote the establishment of wastewater reuse projects for irrigation. This study considers a real DMA in a municipality in Alicante Province (Spain).

The rest of the manuscript is organised as follows: Section 2.1 discusses the differences between the current scenario (*laissez-faire* scenario) and the scenario with a wastewater treatment plant and dual network; the wastewater quality is analysed in Section 2.2; the purification treatment process in a real district metered area (DMA) is discussed in Section 2.3; a monetary analysis is presented in Section 2.4; Section 3 presents the calculations; Section 4.1 describes the actual water pressurised network (WPN) of the proposed system; the construction of a wastewater treatment facility is described in Section 4.2; the reclaimed water delivery system is presented in Section 4.3; the cost data are displayed in Section 4.4; finally, the results are presented in Section 5 along with a step-by-step evaluation, and the conclusions are presented in Section 6.

2. MATERIAL AND METHODS

2.1. Features of the current and future scenarios (WPN and dual network)

The current scenario includes a water pressurised distribution network that supplies water to consumers. The water audit for this WPN is:

$$\forall_{inj} = \forall_{cons} + \forall_{irr} + \forall_{leaks} \quad (1)$$

where, $\forall_{inj}$ the volume injected into the WPN, $\forall_{cons}$ is the volume consumed by residential users, $\forall_{irr}$ is the volume used for the irrigation of urban gardens, and $\forall_{leaks}$ is the volume lost through leakage. The DMA considered herein incorporates a wastewater network that gathers sewage and transports it to the wastewater treatment plant (WWTP). The volume of treated wastewater is assumed to be $Cr \cdot \forall_{cons}$ (where Cr is the return factor equal to the ratio of wastewater flow to water consumption).

In the proposed scenario, two water distribution networks exist: the first (the existing one) which supplies freshwater for purposes other than irrigation (Eq. 2), and the second which supplies reclaimed water for irrigation (Eq. 3). The water audit of the existing network follows Eq. 1, but $\forall_{irr} = 0$. Due to the reduction in volume, an increase in pressure can be expected, resulting in an increase in the volume of water lost through leakage ($\forall_{leaks}^*$).

$$\forall_{inj}^* = \forall_{cons} + 0 + \forall_{leaks}^* \quad (2)$$

$$\forall_{injD} = \forall_{irr} + \forall_{irr-D}^* + \forall_{leaks_D} \quad (3)$$

where, $\forall_{injD}$ represents the reclaimed water volume injected into the dual network, $\forall_{irr}$ and $\forall_{irr-D}^*$ represent the volume used for the irrigation of urban gardens and other crops, and $\forall_{leaks_D}$ represents the volume lost through leakage in the dual WPN. The wastewater network in the proposed scenario transports sewage to the treatment area (not to the WWTP). Notably, the amount of water consumed by the end-users is the same in both scenarios, which implies that the cost of freshwater does not affect the analysis herein.

2.2. Wastewater reclamation and reuse: permitted uses for reclaimed water

Reclaimed water is wastewater that, after undergoing treatment, can be used for various purposes, based on the minimum water quality required for each use. The approval of water quality levels based on usage and treatment processes are stipulated by the European regulations on the reuse of wastewater (EU 2020) and the Spanish regulations on the reuse of wastewater (BOE, 2007), which establishes the legal requirements for the reuse of treated water. These regulations offer a normative framework for new water supply sources that are capable of providing additional water resources. This ensures the release of high-quality water resources for more demanding uses such as public supply, reduces pollutant discharge to natural watercourses (Scott et al., 2004), aids the recovery of nutrients in wastewater through the utilisation of regenerated water for agricultural and gardening irrigation (Jiménez et al., 2010; Vergine et al., 2017), and guarantees long-term water supply.

In this study, the uses of reclaimed water are separated into residential (outdoor irrigation, toilet flushing, washing cars and/or houses), irrigation (municipality consumption in urban green areas), and industrial uses (cooling of manufacturing and industrial processes, and dust control at construction sites). Each use has different quality requirements.

The wastewater treatment plant (WWTP) must follow specific procedures to allow the regeneration of the effluent. It must specify:

- Treated water flowrates.
- Qualities demanded in the reclaimed effluent corresponding to the following limits: *Escherichia coli* (UFC/100 ml), nematode eggs (unit/10 litres), suspended solids (mg/L), and turbidity (NTU)

- Regeneration procedure
- Storage and delivery structures
- Costs of setting up and running the plant

The pollutants to be dealt with include the organic load (biochemical oxygen demand in five days (BOD₅) and chemical oxygen demand (COD)) and suspended solids (SS). Additionally, where necessary, nutrients such as nitrogen (N) and phosphorus (P) must be reduced as well. Table 1 shows the quality requirements for different water uses: (a) domestic wastewater, (b) industrial, livestock, commercial, or service wastewater, (c) rainwater, and (d) clean water that infiltrates the network of collectors from aquifers and other uncontrolled inputs such as streams and public fountains.

Table 1. Quality groups based on established bacteriological limits in R.D. 1620/2007 for different water uses

USES		<i>ESCHERICHIA COLI</i> UFC/100ml	INTESTINAL NEMATODES	LEGIONELLA UFC/100ml
Industrial a)	Cooling towers, evaporative condensers	absence	absence	absence
Urban a) and b)	Private irrigation and toilet-flushing	absence	< 1	< 100
Environmental a)	Direct aquifer discharge	absence	< 1	Not defined
Urban a), b) c) and d)	Urban services, firefighting, and car-washing systems	< 100–200	< 1	< 100
Agricultural a) and recreative a)	Unrestricted agricultural irrigation, golf course irrigation			
Agricultural a), b) and c)	Irrigation of agricultural products for non-fresh human consumption, watering of	< 1000	< 1	Not defined

	pastures for animals, aquaculture			
Industrial	Processing and cleaning water for the food industry			< 100
environmental	Aquifer recharge by percolation	< 1000	No limits	No limits

178

179 A corresponding study of water quality must be carried out based on the population to
180 whom the water is to be supplied. The water quality is determined by the corresponding
181 requirements of the corresponding treatment facilities. The size of the population can be
182 determined based on the number of inhabitants and/or the pollution load, and classified into
183 small, medium, and large populations. The European Union considers small agglomerations to
184 be those with a population of less than 2000 inhabitant equivalents.

185 An inhabitant equivalent transfers pollutants that have a biodegradable organic load with
186 a 5-day biochemical oxygen demand (BOD₅) of 60 g of oxygen per day (1 inhabitant equivalent
187 generates approximately 100 l/d of urban wastewater).

188 Therefore, according to Directive 91/271/EEC, 1991, 12, a small population of 200
189 inhabitants can determine the water quality requirements. The purpose of this Directive is the
190 collection, treatment, and discharge of urban wastewater and the treatment and discharge of
191 water from certain industrial sectors. Thus, the percentage reduction of each of the wastewater
192 parameters is BOD₅ = 70%–90%, COD = 75%, and SS = 70%.

193

194 **2.3. Wastewater treatment**

The wastewater treatment system presented herein is for a wastewater volume of $Cr.V_{cons}$, as stated previously. The purification process is divided into three stages: pre-treatment, primary treatment, and secondary or biological treatment.

The proper execution of the pre-treatment and primary treatment operations is vital for the other components of the treatment plant (Ortega de Miguel et al., 2010). This strategy may be implemented for the wastewater received from small municipalities or DMAs. The pre-treatment stage can include roughing, de-sanding, and degreasing elements, while the primary treatment can be performed in septic or Imhoff tanks, or by decantation.

Secondary treatment of wastewater from small communities can combine intensive technologies such as extended aeration systems (AS), fixed-bed bacteria cultures, trickling filters (TF), rotating biological contactors (RBC), sequential batch reactors (SBR), and moving bed biofilm reactors (MBBR) (Matamoros et al., 2016). This study does not focus on specific technologies but rather on the mechanism needed to obtain the required quality of reclaimed effluents for irrigation (Table 1) according to the stipulated limits: *Escherichia coli* < 100–200 UFC/100 ml; Nematode eggs < 1 unit/10 l; and *Legionella* < 100 UFC/100 ml. Additional demands such as COD = 125 mg/l, BOD₅ = 25 mg/l, SS < 35 mg/l, N < 15 mg/l, and P < 2 mg/l, must be satisfied as well.

2.4. Economic analysis of alternatives

The benefits of installing a treatment plant and a dual network to deliver reclaimed water for irrigation are analysed herein. Considering the cost framework (Cabrera et al., 2013), the fixed costs (construction, asset amortisation, etc.) and social costs are equal in both cases. The variable cost of water depends on the resource itself, the energy required, and the lifespan of the infrastructure. The operation and maintenance costs of the infrastructure (energy cost

linked to pumping, treatment, and transport, which is analogous to the amount of water treated) in the scenarios compared herein are different, and their effect on the environmental costs (as a tax to encourage utility managers to use the proposed system) are assessed accordingly. The environmental costs associated with energy (greenhouse gas emissions, carbon credits, and CO₂ emissions) are not considered herein.

In addition to the cost of the equipment that must be purchased initially, the total cost of the dual network infrastructure (civil work, piped irrigation network, land, and asphalt), electrical devices, removal of vegetation, health and safety of the workers while laying the new pipelines, solid waste handling and individual safety material, indirect costs, and taxes must be considered while evaluating the feasibility of constructing a treatment plant and dual pressurised network. In addition, the wastewater treatment plant, which consists of structures for pre-treatment, primary treatment, and secondary treatment, a tank for storing the reclaimed water, pipelines, and measurement, control, and monitoring devices, must be constructed as well.

The proposed system provides monetary savings on account of lower freshwater consumption and lesser wastewater treatment in the WWTP (an aggregate cost). For comparison, the costs are presented in current financial units using the equivalent continuous discount rate r (Kleiner and Rajani, 2001). The objective function is the net present value (NPV), which considers the current investments (t_p) and the future earnings after a time t .

$$NPV = \left[-I_0 + \int_{t_p}^t (C_W * (\forall_{inj} - \forall_{inj}^*) C_{EN} (E_1 - E_1^* - E_d) + (C_{ENV} * \forall_{inj} + C_{WR} * (\forall_{irr} + \forall_{irr-D}^*) + C_S * Cr. \forall_{cons}) - C_m^*) \cdot e^{-rt} dt \right] = \left[I_0 + \int_{t_p}^t S_i \cdot e^{-rt} dt \right] \quad (4)$$

where, (C_W) and (C_{EN}) are the water and energy costs, respectively; E_1 is the energy consumed by the WPN in case 0; E_1^* and E_d are the energy consumed by the WPN and the dual network, respectively; I_0 is the purchase achieved in year zero; and S_i is the economic savings.

The cost of water reclaimed (C_{WR}), the environmental cost (C_{ENV}), and the sanitation costs (C_S), must be calculated, along with the volume used for the irrigation of urban gardens and other crops ($\forall_{irr}$; $\forall_{irr-D}^*$), the volume injected into the WPN (case 0) $\forall_{inj}$, the volume injected into the WPN (future case) $\forall_{inj}^*$, and the water treated in the wastewater treatment plant $Cr \cdot \forall_{cons}$. The extra maintenance is incorporated with the value C_m^* . These figures are equivalent to the pump energy consumption (E_P). Equating the derivative of Eq. 4 to zero, the payback period can be calculated as:

$$T_i = \frac{-1}{r} \cdot \ln \left(1 - \frac{r \cdot I_0}{S_i} \right) \quad (5)$$

where, T_i (in years) is the payback period. The smaller the value of this criterion, the greater the energy savings per monetary unit devoted to the purchasing apparatus. Based on these numbers, the environmental costs to compensate for the investment in t_r^* years, is:

$$C_{ENV} = \frac{1}{\forall_{inj}} \left[\left(\frac{r \cdot I_0}{1 - e^{-r t_r^*}} \right) + C_m^* - C_W * (\forall_{inj} - \forall_{inj}^*) - C_{EN}(E_1 - E_1^* - E_d) - C_{WR} * (\forall_{irr} + \forall_{irr-D}^*) - C_S * Cr \cdot \forall_{cons} \right] \quad (6)$$

This represents the value that must be paid by the utility manager to compensate for the use of freshwater for irrigation.

3. CALCULATION PROCESS

The process to calculate the environmental costs is described in this section here (Figure 1).

Step 1, Current case input data: This project requests having a calibrated water model which reflects the current state of the WPN. The model must have no errors when running this hydraulic simulation (frequent inaccuracies in models are negative pressures, separated junctions/tanks/reservoirs). The user must know some more data as the return factor Cr (wastewater flow divided by water consumption).

Step 2, Current case calculation: The water audit is calculated. The user may determine the $\forall_{inj}$ the volume injected into the WPN, $\forall_{cons}$ the amount consumed by residential purchasers and the $\forall_{irr}$ the quantity used in irrigation of the urban garden. The volume wasted through breaks ($\forall_{leaks}$) is considered. If hydraulic software is EPANet (Rossman, 2000), the most widely used software for urban WPN, we may establish leakage by exploiting the UAleaks software (Pardo and Riquelme, 2019). The energy taken by the WPN in case 0 (E_1) is calculated herein.

Step 3 Building the future case:

This project demands to create two calibrated water models describing a future state. The first is like the preceding one (Case 0) excluding the volume handled in irrigation of the urban garden ($\forall_{irr}=0$); an amount delivered by the dual network. The dual pressurized network delivers reclaimed water and the volume injected is corresponding to ($\forall_{inj-D} = Cr * \forall_{cons}$). Both models must contain no errors and bring us successful hydraulic calculations (as in step 1).

Step 4, Future case calculation: The water and energy audits of the two WPN built in Step 3 is calculated to get the volume ($\forall_{inj}^*$, $\forall_{irr}$ and $\forall_{irr-D}^*$) and the energy consumed in WPN (without considering freshwater to irrigation) E_1^* and in the Dual network E_d .

Step 5, Economic Input data: The economic input data required here are:

- r , equivalent continuous discount rate (-)
- Energy costs ($C_{EN} = \text{EUR/Kwh}$)
- I_0 is the investment performed in year zero. This value includes every cost described before build a dual pressurized network and a treatment plant.
- t_r^* (years), the number of years required to compensate for the investment.

- C_W Cost of freshwater in EUR/m³.
- C_{WR} Cost of the reclaimed water in EUR/m³.
- C_S Sanitation costs in EUR/m³.

Step 6, Economic Calculations. Finally, the environmental cost is calculated for the values selected. The minimum value of the environmental cost, the most efficient the alternative is.

Figure 1. Flowchart of the calculation process

4. CASE STUDY

4.1. WPN layout

The network is designed with pipes with a nominal diameter of 100 mm (FD-C 100 NT-HP BZN e6.1 JE. DN 100L6) and a thickness of 6 mm. It is considered that there are 50 homes

and 200 inhabitants in this area of a town located in Alicante province. The green area (Figure 2) corresponds to 0.21 hectares, taking into account the consumption of the flora of the location, it will correspond to a different daily consumption, Tree: 10.5 l/day; grass, 7 l/m² and palm tree: 1.8 l/m². Water supplied comes from a reservoir (elevation 43.34m) and by pumping device (CR 64-1-1A-F-A-E-HQQE; Grundfos). The return factor (wastewater flow divided by water consumption) is $Cr=0.8$.

Figure 2. The general layout of the network.

The process followed to recycle water is described here. We take common urban wastewater (Ortega de Miguel et al., 2010) (Table 2).

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Table 2 Typical composition of wastewater effluent.

Parameter	Wastewater effluent (mg/l)
Suspended solids	250
BOD ₅	300
COD	600
N-NH ₄ ⁺	30
N	50
P	10
Faecal coliforms	10 ⁷

318

319 **4.2.1. Pretreatment**

320 The structure includes a structure of grids (inclined steel bars) spaced across the
 321 conveying through which the wastewater moves. We refer the grates used here are rough and
 322 fine sediments. The difference between the two is the removal of material dealing with its size.
 323 The wastewater velocity must avoid waste and sand deposition.

324

325 **4.2.1. Primary treatment**

326 We use Imhoff Tanks for the primary treatment of wastewater generated in individual
 327 residences and small population facilities which lack nearby sewage networks. Besides, the
 328 Imhoff Tanks offer anaerobic stabilization of the sludge. The maximum design capacity of Imhoff
 329 tanks ranges below a population of 1000 equivalent inhabitants.

330

331 **4.2.1. Secondary treatment**

332 Rotating Biological Contactors (RBC) are wastewater treatment systems in which it
 333 attaches pathogens to a carrier media, which rotates semi-immersed (40% of its surface area)
 334 in the wastewater. These practices describe a specialized choice to the conventional Active
 335 Sludge process (Cortez et al., 2008). In recent years, RBCs have been exploited to treat various
 336 types of wastewater, including urban wastewater (Akunna and Jefferies, 2000; Grady Jr, 1982;

Nowak, 2000). By turning slowly (1-2 rpm), it exposes its surface to water and air. A film of bacterial biomass develops on the surface, using the soluble organic matter present in the wastewater as a substrate and getting in the oxygen indispensable for respiration from the atmospheric air during the state when the surface is out of the water (Scholz, 2006).

4.3. Dual pressurized network

Once the wastewater treatment process has been completed, the reclaimed water is stored in a tank for later use. Irrigation occurs twice per day (every 12 hours) to decrease tank size. The green areas of the case study are irrigated first, and the surplus volume will be used for watering the surrounding green areas. We design the irrigation network with 700m of pipes with a nominal diameter of 100 mm (pipe FD-C 100 NT-HP BZN e6.1 JE. DN 100L6) and a thickness of 6 mm. The pump is (CR 64-1-1A-F-A-E-HQQE; Grundfos). The green area irrigated corresponds to 0.21 hectares Figure 3.

Figure 3. Layout Dual network

4.4. Cost data

The investment required for the wastewater treatment and dual network involves civil work, pipes irrigation network, wastewater regeneration, land and asphalt, demolitions, collective protection, individual protection equipment, indirect costs and taxes, resulting in a quantity of $I_0=624970.52$ EUR.

The maintenance costs of the wastewater treatment plant (Ortega de Miguel et al., 2010) is summarized in Table 3. With these numbers, we consider the yearly maintenance cost as $C_m^*=11780$ EUR/y.

Table 3. Management and operation costs for an Inhoff tank and an RBC

Treatment	Operation	Costs	Frequency	Annual costs
Pre	Cleaning pre-treatment system	16 (EUR/h)	Twice/week	416
	Inspection and measurement	16 (EUR/h)	Twice/year	32
	Sludge removal	15 (EUR/m ³)	Twice/year	2250
Primary	Sludge removal	15 (EUR/m ³)	Once/week	8250
Secondary	Checking rotation and purge decanter	16 (EUR/h)	Three times/week	832

Sanitation cost is $C_S = 0.74$ (EUR/m³) (Jodar-Abellan et al., 2019b), the cost of the reclaimed water $C_W = 1.22$ EUR/m³ (García-Rubio et al., 2015), the cost of the reclaimed water $C_{WR} = 0.015$ EUR/m³ (Mas Ortega, 2016), $r=2\%$ equivalent continuous discount rate, energy costs, $C_{EN} = 0.1$ EUR/Kwh, number of years required to compensate the investment, $t_r^* = 5$ y.

5. RESULTS AND DISCUSSION

5.1. Calculation of the current and future state.

We calculate the water and energy consumption in the current (WPN) and the future state (WPN for human consumption and dual network). These results show the future scenario involves higher energy consumption (recycled water should be delivered to crops) Table 4.

Table 4. Water and energy audit results

	Current State	Future state	
	WPN	WPN*	Dual Network
V_{inj} Injected water (m ³)	129.68	129.15	103.32
V_{cons} Consumed water (m ³)	129.15	129.15	-
V_{irr} Volume irrigation (m ³)	0.5263		0.53
V_{irr-D}^* Volume irrigation other crops (m ³)	-	-	102.80

Ep (kWh) Energy required	7.690	7.66	5.63
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5.2. Reclaimed water

In Table 5, we show the quality values got after the treatment process. We may see that the final effluent values are lower than the concentration allowed.

Table 5. Pollutants concentration of the effluent

	Inhoff tank		RBC		
Param.	% Reduction	Final eff. (mg/l) (T.1º)	% Reduction	Final eff. (T.2º) (mg/L)	Max. Conc. (mg/L)
COD	-	184.132	70-90	55.239	125 mg/L O ₂
BOD ₅	30-65	64.446	80-98	12.889	25 mg/L O ₂
SS	35-85	68.386	75-98	17.096	35 mg/L (d)
N	0-60	13.153	30-80	9.206	15 mg / L
P	0-75	2.630	25-30	1.927	2 mg/L

5.3. Economic analysis

Now that we know the investment ($I_0=624970.52$ EUR), we must calculate the monthly savings obtained. The monthly energy savings are:

$$(C_{EN}x(E_1 - E_1^* - E_d)) = 0.1 x(7.69 - 7.6588 - 5.634) x30 = -16.80 \text{ EUR}/m$$

As this value is negative, it means that we consume more energy than before.

The monthly savings which come from saving freshwater is equal to:

$$(C_Wx(\nabla_{inj} - \nabla_{inj}^*)) = 1.22x(129.68 + 129.15)x30 = 19.398 \text{ EUR}/m$$

The monthly savings which come from selling water reclaimed:

$$(C_{WR}x(\nabla_{irr} + \nabla_{irr-D}^*)) = 0.015 * (0.53 + 102.80)x30 = 46.4985 \text{ EUR}/m$$

The sanitation cost savings are:

$$(C_S \times C_r \times V_{cons}) = 0.74 \times (0.8 \times 129.15) \times 30 = 2293.704 \text{ EUR/m}$$

The operation costs (a value negative as maintenance costs are now higher) are:

$$(-C_m^*) = \frac{11780}{12} = -981.66 \text{ EUR/m}$$

In short, we substitute the above-mentioned values in equation 4:

$$\left[-624970.52 + \int_0^{5 \times 12} (1361.1 + C_{ENV} * 129.68 * 30) x e^{-0.02t/12} dt \right] = 0$$

Being the $(1341.7 + C_{ENV} \times 129.68 \times 30)$ the monthly economic savings. Note that the interest rate is $r=2\%$ per year, and in this formula, we use $r=0.02/12$ as we want the monthly value. We can solve this equation or equation (6)

$$C_{ENV} = \frac{1}{129.68 \times 30} x \left[\left(\frac{\frac{0.02}{12} * 624970.52}{1 - e^{-0.02 * 5}} \right) - 1361.1 \right] = 2.46 \text{ EUR/m}^3.$$

5.4. Sensitivity analysis

The calculations were reproduced for other payback periods, to obtain the following values, Figure 4.

Figure 4. Environmental cost (EUR/m³) variation

The influence of the continuous discount rate r is also considered by introducing the values of $r = 2\%$, $r = 3\%$, and $r = 4\%$.

Table 6 Environmental cost for different values of —equivalent continuous discount rate— r and payback period.

T	$r=2\%$	$r=3\%$	$r=4\%$	T	$r=2\%$	$r=3\%$	$r=4\%$
2	6.21	6.28	6.34	7	1.68	1.75	1.82
3	4.13	4.20	4.26	8	1.45	1.52	1.59
4	3.07	3.13	3.20	9	1.27	1.34	1.41
5	2.46	2.49	2.56	10	1.12	1.19	1.27
6	1.99	2.06	2.13				

The payback period for the environmental costs in Denmark ($C_{ENV} = 0.84$) and $r = 2\%$ are calculated below. The environmental savings are equal to $C_{ENV} \times V_{inj} = 0.84 \times 129.68 \times 30 = 3267.93$ EUR. Therefore, the monthly savings are $(1341.7 + 3267.93 = 4609.63)$ EUR

$$T_i = \frac{-1}{r} \cdot \ln \left(1 - \frac{r \cdot I_o}{S_i} \right) = \frac{-1}{0.02/12} \cdot \ln \left(1 - \frac{\frac{0.02}{12} * 624970.52}{4690.63} \right) = 153.68m = 12.8 y$$

6. CONCLUSIONS

Reclaimed wastewater can be used for non-potable applications to reduce freshwater consumption. However, the potential of this water source has not yet been fully exploited (in Spain, only 10.8%–13% of the total sanitation water is reused). Owing to the prolonged water scarcity in Alicante, nearly 42% of sanitation water is reused. Agriculture has the largest demand for water and consumes almost 70% of all water. Therefore, there is an urgent need to encourage utility managers to promote the use of reclaimed water in irrigation. Furthermore, a procedure to determine an environmental tax that must be paid by utility managers for not using recycled water was established herein. This can reduce freshwater consumption and promote the use of reclaimed water in agriculture.

The results indicated that the proposed treatment plant is impractical now. This study considered low prices for reclaimed water (0.015 EUR/m³) and symbolic benefits. Consequently, due to the rising operating costs of the wastewater treatment plant and the small population size of the case study, the proposed system cannot benefit from economies of scale. Only the sanitation costs could be recovered due to consumer support. Thus, the proposed approach is only suitable in areas with water scarcity that have significant water costs (water obtained from low aquifers or desalination plants). As only a small amount of freshwater is

required to irrigate the urban areas in the case considered herein, the water savings are negligible.

However, there is still a need to shift towards a modern water supply scheme that promotes the establishment of such systems. The environmental tariff recommended herein for using freshwater for irrigation can increase the feasibility of such projects.

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