Indirect costs and benefits evaluation on reclaimed water distribution systems

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Abstract

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Nowadays, it has been an increasing usage of reclaimed water for several urban uses motivated by the scarcity of potable water and to ensure the protection of water resources by reducing effluent discharges in the environment. The usage of reclaimed water contributes for water resources sustainability ensuring current water demand without compromising future generations' needs.

The usage of reclaimed water has numerous environmental benefits, however, in the past, few cost-benefit analysis accounted for indirect benefits and costs associated with these projects.

A methodological framework is presented for the evaluation of those externalities based on the literature reviewed.

It was carried out the CBA methodology to 10 reclaimed water projects located in Cascais. There were considered all the benefits and costs associated with those projects, including externalities.

The CBA was conducted for a time horizon of 40 years, and the financial and social discount rates of 5,5 and 5% were adopted. The outcomes showed that 6 out of 10 projects were economically feasible. Additionally, the sensitivity analysis showed that the investment costs and revenue have a significant impact on economic NPV, changing it up to 69,83%.

1. Introduction

Nowadays, the lack of fresh water is one of humanity's biggest challenges. Even though 70% of our planet is water, only 2.5% is fresh water. Moreover, most of the fresh water is in its solid state (1.8 %); therefore, it is not available for human consumption. As a result, only 0.7% of the planet's water enables life (National Water Organization, n.d.).

Freshwater is not equally available all year long due to climatic seasonality. That said, also freshwater needs are not constant. Usually, the demand is higher in the warmer months, where there is a lack of precipitation and high evaporation. This unbalance becomes more significant in drought years. The main economic activities responsible for the increase in the demand for freshwater are tourism and agriculture. In addition, extreme weather events associated with climate change, such as droughts and flooding, contribute to water availability reduction. That said, droughts reduce freshwater availability, and flooding decreases the water's quality (APA, 2019; ERSAR, 2010).

The World Resources Institute conducted a study that shows that in 2040 there will be 26 countries in high hydric stress. Portugal will be among this group of countries whose water needs represent 40% to 80% of the average water availability. Therefore, these countries become vulnerable to droughts or spikes in water consumption. In the recent past, there are several examples of countries that went through this situation such as, California (2015), Rome (2017), Cape Town (2018), or, more recently, Chennai (India), in 2019, which was forced to rationalize the water supply to the population as its hydric resources hit concerning low levels (Dias & Correia, 2020).

Since the beginning of the XXI century, there has been an urgent concern with the sustainable management of hydric resources (ERSAR, 2010). Wastewater reuse is considered a focal point in the sustainable management of hydric resources. However, in Portugal, the use of reclaimed water is still overlooked, even in high hydric stress regions (ERSAR, 2020).

Several reasons explain this situation, such as lack of legislation until 2019, lack of knowledge by the society about reclaimed water, and the high costs associated with the necessary improvements in the Wastewater treatment plant (WWTP) to produce and distribute the reclaimed water from the WWTP to the consumer. Furthermore, in Portugal, the largest WWTPs are situated near the coastline, whereas the most significant potential consumer, the agriculture sector, is located in the interior.

Legislation on the production and usage of reclaimed water only came about in 2019, with DL n.º 119/2019 of August 21. This legislation establishes a fit-for-purpose approach in which specific rules are applied depending on its use.

There are multiple uses for reclaimed water that do not compromise public health or the environment. Water reclamation must be seen as a resource that enables high water-demanding projects and, at the same time, has positive environmental impacts such as decrease discharge to sensitive water bodies and decrease the diversion of fresh water from sensitive ecosystems (APA, 2019).

In Portugal, there are few WWTPs capable of producing reclaimed water. For example, in 2019, only 32 produced this resource, which corresponds to 8.4 million cubic meters of reclaimed water, which is only 1.2% of the total treated wastewater (ERSAR, 2020).

However, around the world, several countries have been reclaiming water for many years. This practice is common in countries with hot and dry climates. In Israel, about 90% of the treated wastewater is reused, and agricultural irrigation is the primary use (Fluence, 2020). China, for example, in 2015, consumed 550 000 million cubic meters of reclaimed water (Zhu & Dou, 2018) . Beijing is China's leader in water reclamation. In 2010, the city reclaimed 680 million cubic meters, 47 % in agricultural irrigation, 30% in environmental reuses, 20% in industrial reuses, and 3 % in several urban reuses (Fan et al., 2015). In the

United States of America, the usage of reclaimed water for nonpotable uses is well accepted, even though it just corresponds to under 1% of the country's water consumption (National Research Council et al., 2012). In Spain, the average reusing rate is around 10%, Murcia Region being the country's most significant consumer with 71.8% (SUWANU, 2020).

2. Methodology

Cost-benefit analysis is an objective and systematic approach to decision-making. Public agencies and businesses use it to evaluate whether the benefits of an action outweigh the costs in monetary terms. Therefore, this methodology enables the investor to verify the financial and economic viability of an investment project. Moreover, the cost-benefit analysis enables the best project choice in terms of 3 variables: financial, social-economic, and environmental. Several concepts are associated with this methodology, such as opportunity-cost, long-term perspective, decision-making indicators, microeconomic approach, and incremental approach (European Commission, 2014).

3. Case study: water-reuse projects in Cascais

The economic, social, and environmental feasibility of 10 potential water-reuse projects in Cascais was evaluated in this case study. These projects would use reclaimed water from Guia's Waste Water Treatment Plant (WWTP) for several uses, such as landscape irrigation of parks and golf courses, street cleaning, and garbage cans' washing. These projects consist of building a distribution system of reclaimed water from the WWTP liquid stage (projects 1 to 8) or the solid stage (projects 9 to 10) to several consumption sites.

4. Results and discussion

4.1. Benefit analysis

4.1.1. Direct benefits

Direct benefits are an immediate result of project implementation and allow the project promotor to cover the incurred costs (Medellín-azuara et al., 2011).

The revenues resulted from reclaimed water sell is one of those benefits. Revenues were estimated for each project, considering a 40 years time horizon. The following expression was used (4.1).

$$R_i = C_i T \quad (4.1)$$

R_i – Revenue from project i (€); C_i - Anual Consumption of project i (m^3/year); T – Tariff (€/m^3)

It was considered a tariff of 0.4 €/m^3 for all reclaiming projects. The annual revenue of each project results from the multiplication of the annual consumption by the tariff. Notice that there is a direct association between the revenue and the consumption of each project, being as much higher as the project consumption.

On the other hand, water savings resulted from reclaimed water usage in irrigation (B_1) instead of potable water are another direct benefit. This benefit was estimated using the equation from Fan et al. (2015), equation (4.2)

$$B_1 = \sum_{i=1}^{n} (T_{p,i} - W_{p,i}) Q_i \quad (4.2)$$

$T_{p,i}$ – tap water price for project i (€/m^3); $W_{p,i}$ – corresponding market price of reclaimed water (€/m^3);

Q_i – amount of reclaimed water for irrigation (m^3)

The water-saving benefit is derived from the difference between the tap water and the reclaimed water price multiplied by the annual reclaimed water volume applied in each project. It was considered a tap water price of 0.6332 €/ m^3 for the uses associated with those projects (Water of Cascais, 2021). Moreover, it was adopted 0.4 €/ m^3 for the reclaimed water price. The benefit resulting from water-saving was estimated at 0.2332 €/ m^3.

The fertilizer savings resulting from the use of this resource was another benefit identified. The use of reclaimed water in landscape irrigation reduces the need for fertilizer applications as the reclaimed water contains plant nutrients such as nitrogen (N) and phosphorus (P). Guia WWTP's reclaimed water has 0.73 mg/L of total phosphorus (P) and 11.3 mg/L of nitrogen (N). This benefit was estimated by applying the Fan et al. (2015) expression (4.3).

$$B_2 = \sum_{f=1}^{m} Q_{irr} C_f P_f \quad (4.3)$$

Q_{irr} – Amount of reclaimed water for irrigation (m^3); C_f – concentration of fertilizer f (mg/L);

P_f – Price of fertilizer f (€/ton)

Fertilizer savings were estimated by multiplying the annual volume of reclaimed water of each project by the fertilizers' concentration and by the reclaimed water price. Several fertilizers prices' were obtained by two fertilizer suppliers, Coelho Pereira, Lda, and Borrego Leonor&Irmão, S.A. By multiplying the nitrogen (N) and phosphorus (P) quantities of the fertilizers by its price, the average price of N and P was estimated. The benefit resulting from fertilizer savings was estimated in 0.001 €/m^3.

4.1.2. Indirect benefits

In economics, the indirect effects of economic decisions are called externalities. Externalities occur when several effects of a transaction are not reflected in the market price of goods and/or resources. In the case of indirect or external benefits, the project promotor does not receive the true worth of the action, and external entities are indirectly benefited.

The implementation of reclaimed water projects results in environmental benefits that are rarely accounted for in the respective CBAs.

One of those benefits is the reduction of effluent discharges on the environment (B_3), preventing the environmental pollution caused by those discharges enhancing the water quality. The Molinos-Senante et al. (2011) equation was used to estimate this benefit (4.4).

$$B_3 = \sum_{j=1}^{j} q_j VP_j \tag{4.4}$$

q_j = shadow price of the pollutant j (€/Kg); VP_j = volume of the pollutant j removed (Kg/year)

It was assumed that the shadow price of each pollutant was equal to the sewage discharge fee applied to each pollutant. According to the Portuguese environmental authority (APA), the fees for discharge of pollutants to water bodies are levied in accordance with the type of pollutants and quantity of pollutants discharged. It was obtained the values of 0.18 €/Kg, and 0.22 €/Kg for the nitrogen (N) and phosphorus (P) discharges fees, respectively. The ammout of pollutants discharge in the water bodies was assumed to be equal to the maximum legal value allowed, which is 15 mg/L for N and 10mg/L for P. Applying those values in the expression (4.4) results in an environmental externality of 0.0027 €/m^3.

Irrigation with reclaimed water has both potential positive and negative impacts on the groundwater aquifers. On the one hand, it contributes to groundwater recharge (B4), but on the other hand, it contributes to groundwater contamination associated with nitrogenous leaching.

Environmental benefits associated with groundwater recharge (B4) were evaluated applying the Fan et al. (2015) expression (4.5).

$$B_4 = Q_r V \tag{4.5}$$

Q_r – amount of reclaimed water using for recharging groundwater (m^3); V – average unit cost of utilizing the groundwater (€/m^3);

According to Almeida et al. (2000) groundwater recharge rate in Cascais is approximately equal to 30% of the precipitation. Furthermore, according to APA the groundwater exploitation fee is 0.0034 €/ m^3. Applying the Fan et al. (2015) expression (4.5) resulting in 0.0010 €/m^3 for this environmental externality. In Table 4.1 it is synthetized the main direct benefits and externalities.

Table 4.1 – Case study direct benefits and externalities

Project	Consumption (m^3/year)	Direct benefits				Externalities		
		Revenue (€)	B1 (€)	B2 (€)	Total (€/year)	B3 (€)	B4 (€)	Total (€/year)
1	25 000	10 000	5 830	26	15 856	68	26	93
2	70 000	28 000	16 324	73	44 397	189	71	260
3	76 000	30 400	17 723	79	48 202	205	78	283
4	12 000	4 800	2 798	13	7 611	32	12	45
5	88 000	35 200	20 522	91	55 813	238	90	327
6	15 000	6 000	3 498	16	9 514	41	15	56
7	91 000	36 400	21 221	95	57 716	246	93	339
8	1 216 306	486 522	283 643	1 263	771 428	3 284	1 241	4 525
9	19 000	7 600	4 431	20	12 051	51	19	71
10	457 789	183 116	106 756	476	290 348	1 236	467	1 703

4.2. Cost analysis

4.2.1. Direct costs

In this case study, costs related to the initial investment, operation and maintenance, and project financing were considered direct costs.

4.2.1.1. Investment costs

The costs associated with acquiring tangible assets required for the project are usually regarded as investment costs. Therefore, investment costs are usually those related to acquiring the land and necessary equipment and facilities construction (European Commission, 2014).

In this case study, it was assumed a three-year span for the reclaimed water distribution system construction; therefore, the investment costs were distributed for that period. In those are included construction and pipeline network installation costs and pumping station costs. Regarding the pumping station, there were considered the following costs: facilities construction, acquisition and installation of the pumps, and the respective electric system. The pumps acquisition costs were provided by (Grundfos (Portugal), SA). The rest of the costs above were obtained in the Water Services and Waste Authority (ERSAR) application developed for water-providing systems.

4.2.1.2. Operation and maintenance costs (O&M)

Operation and Maintenance Costs are related to the daily operation of the facilities and the consequent necessary maintenance. These costs are usually divided into fixed and variable. Fixed costs are those that are not dependable on the amount of product made or service provided. Variable costs are the opposite, given that they depend on the amount of product made or service provided (European Commission, 2014).

In this case study, the O&M were calculated, considering the pumps and pipeline operation and maintenance costs and the pumping station electricity costs. That said, the pipeline's O&M annual costs were estimated to be 1.5% of its construction and installation costs. Likewise, the pump's annual O&M costs were estimated to be 3.5% of its acquisition cost. On the other hand, the electricity costs were estimated regarding the necessities of each project, using the following equation (4.6).

$$C_{energy} = C_u \frac{\gamma H \forall_{pump}}{\eta} \quad (4.6)$$

C_u – electricity costs (0.1 €/kWh); γ – water specific weight (9.8 KN/m^3); H – pumping height (m); $\forall_{pump}$ - annual volumetric flow rate (m^3); η – pump efficiency

For every project, it was considered an electricity cost of 0,10 €/KWh. However, when it comes to pumping height (H), annual volumetric flow rate ($\forall_{pump}$), and pump efficiency (η) there are specific values for each project depending on their characteristics. Moreover, the annual volumetric flow rate ($\forall_{pump}$) is equal to multiplying the diary consumption of each project by the 180 days of irrigation.

4.2.2. Indirect Costs

Indirect costs are external costs that are not reflected in the project's direct costs (Medellín-azuara et al., 2011).

Reclaimed water irrigation have a potential negative impact on the environment, specifically in groundwater aquifers. This is because nutrients such as nitrogen are present in reclaimed water and can cause nitrate leaching of soil, harming the environment. However, there is not enough data to estimate this variable's monetary impact in this case study, so it was not considered. Furthermore, there was no evidence in the literature consulted that this negative externality had a significant impact on the financial and economic feasibility of the projects.

4.3. Cost-benefit analysis (CBA)

4.3.1. Financial analysis

The financial analysis is based on the discounted cash flow method and evaluates the financial feasibility of the water-reuse projects accounting for all the direct costs and benefits. It was considered a 40 years time horizon (TH) and a financial discount rate (FDR) of 5.5%. Time horizon is the number of years for which project cash-flow forecasts are provided and corresponds to his useful life. The financial discount rate reflects the opportunity cost of capital. Finally, it was calculated the financial performance measured by the financial net present value (FNPV) and the financial rate of return (FRR) for each project to evaluate their feasibility (Table 4.2).

Table 4.2 – Financial analysis

Project	Financial analysis						
	TH (years)	FDR (%)	Investment (€)	O&M (€)	Direct Benefits (€)	FNPV (€)	FRR (%)
1	40	5,5	266 037	51 525	223 289	-94 273	2,58
2			349 378	70 602	625 210	205 230	9,43
3			357 405	72 931	678 799	248 462	10,09
4			228 133	43 942	107 179	-164 895	-1,79
5			417 381	87 124	785 978	281 473	9,96
6			390 305	79 395	133 973	-335 727	-4,62
7			578 402	126 620	812 773	107 750	6,83
8			900 265	476 043	10 863 518	9 487 210	50,17
9			697 627	148 337	169 700	-676 265	-
10			1 932 928	560 175	4 088 773	1 595 670	10,86

4.3.2. Economic analysis

The economic analysis is also based on the discounted cash flow method and evaluates the economic feasibility of the water-reuse projects accounting for all costs and benefits including externalities. It was also considered a 40 years time horizon (TH) and a social discount rate (SDR) of 5%. The social discount rate reflects the social view on how future benefits and costs should be valued against present ones. Finally, it was estimated the economic net present value (ENPV) and the economic rate of return (ERR) for each project to evaluate their feasibility (Table 4.3).

Table 4.3 – Economic analysis

Project	Economic analysis							
	TH (years)	SDR (%)	Investment (€)	O&M (€)	Direct benefits (€)	Externalities (€)	ENPV (€)	ERR (%)
1	40	5,0	267 385	55 459	240 339	1 410	-81 096	2,62
2			351 219	75 993	672 949	3 947	249 684	9,50
3			359 308	78 500	730 630	4 285	297 108	10,16
4			229 262	47 297	115 363	677	-160 519	-1,75
5			419 559	93 777	845 993	4 962	337 619	10,03
6			392 210	85 458	144 203	846	-332 618	-4,57
7			581 396	136 288	874 834	5 131	162 280	6,89
8			906 255	512 392	11 693 025	68 583	10 342 961	50,39
9			700 975	159 664	182 658	1 071	-676 910	-9,66
10			1 943 005	602 949	4 400 980	25 813	1 880 839	10,93

4.3.3. Sensitivity analysis

There is a certain degree of uncertainty associated with the estimates of several variables in the water-reuse projects. The fact that some of the assumptions made in the estimates were dependent on market conditions which are constantly changing makes impossible to eliminate that uncertainty (Silva et al., 2018). Sensitivity analysis enables the identification of the critical variables of the project. Such variables are those whose variations, whether positive or negative, have the largest impact on the project's financial and/or economic performance. For simplification reasons, it was assumed that the critical variables were tariff and investment costs. It was created three scenarios, base/probable, pessimist, and optimist. The base scenario corresponds to the costs and benefits estimated in economic analysis. The pessimist scenario corresponds to investment costs being 10% higher and tariffs 10% lower; in other words, revenues 10% lower. Finally, the optimist scenario corresponds to investment costs being 10% lower and tariffs 10% higher; in other words, revenues 10% higher. The results of the sensitivity analysis on ENPV (Table 4.4) and ERR (Table 4.5) are shown below.

Table 4.4 - Sensitivity analysis (ENPV)

Project	ENPV				
	Variation (%)	Pessimist (€)	Base/Probable (€)	Optimist (€)	Variation (%)
1	-51,66	-122 992	-81 096	-39 199	51,66
2	-31,06	172 120	249 684	327 247	31,06
3	-27,60	215 098	297 108	379 118	27,60
4	-18,82	-190 721	-160 519	-130 317	18,82
5	-28,23	242 309	337 619	432 930	28,23
6	-14,53	-380 934	-332 618	-284 302	14,53
7	-69,83	48 967	162 280	275 594	69,83
8	-8,01	9 514 883	10 342 961	11 171 040	8,01
9	-12,06	-758 528	-676 910	-595 293	12,06
10	-25,09	1 408 979	1 880 839	2 352 700	25,09

Table 4.5 - Sensitivity analysis (ERR)

Project	ERR				
	Variation (%)	Pessimist (%)	Base/Probable (%)	Optimist (%)	Variation (%)
1	-40,07	1,57	2,62	3,78	44,12
2	-16,49	7,93	9,50	11,30	18,94
3	-16,04	8,53	10,16	12,03	18,45
4	-52,22	-2,66	-1,75	-0,79	54,91
5	-16,13	8,41	10,03	11,89	18,55
6	-21,55	-5,55	-4,57	-3,59	21,45
7	-19,57	5,54	6,89	8,42	22,20
8	-10,97	44,86	50,39	56,64	12,40
9	-23,44	-11,93	-9,66	-8,07	16,52
10	-15,83	9,20	10,93	12,92	18,25

5. Conclusions

The Cost-Benefit Analysis methodology was used to study the social, economic, and environmental feasibility of 10 water-reuse projects that used reclaimed water from Guia WWTP in Cascais for several purposes. Some of these purposes are, landscape irrigation of parks and golf courses, street cleaning, and garbage cans' washing. Looking at the results of the economic analysis (Table 4.3), a conclusion was made that 6 out of 10 projects were economically feasible. The profitability of project 8 was the most relevant, with a 10 342 961.40 € ENPV and a 50,4% ERR. Therefore, it is concluded that projects number 2, 3, 5, 7, 8 and 10, should be implemented because of their social and environmental benefits. However, the impact of the positive externalities on economic feasibility is not as relevant as the impact of direct benefits, although its important impact on society and the environment. On the other hand, consumption is the most impactful variable in the project's feasibility. Therefore, it is verifiable that there is a direct correlation between consumption and the respective value of ENPV and also that economically feasible projects are the ones that are associated with higher consumption and consequently higher revenues.

In the sensibility analysis, a conclusion was made that projects that already were economically feasible in the base/probable scenario are still feasible, even in the pessimist scenario, which shows that the risk associated with these projects is low. However, the impact of the different scenarios (Pessimist and Optimist) in the values of ENPV and ERR of the different projects is not the same. The observed variation in ENPV and ERR values between the Pessimistic/Optimistic scenarios and the base scenario is between 8.01% and 69.83%, for ENPV, and between 10.97% and 52.22%, for ERR. Therefore, it is concluded that the impact of the variation of cost of investment and revenue variables is more significant in some projects than in others.

Future Developments

It was assumed a tariff of 0.40 €/m^3 to estimate the revenues derived from the reclaimed water sales**.** This rate was considered an adequate estimation because it is inferior than public water's current price. However, it may not be the most accurate, so it is suggested that future studies use stated preference methods to obtain more accurate variable values.

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