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Reclaimed water and irrigation: a cost-benefit analysis for desalination of WWTPs effluents

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ABSTRACT

The increase of salts both in soils and water for irrigation purposes is a growing problem for farmlands. Waster stress in arid and semi-arid regions encourages the use of non-conventional water sources, such as wastewater reuse. Current wastewater treatment plants (WWTPs) are unable to reduce salinity because they are designed to remove the organic fraction from the wastewater. Hence, effluent contains high amount of salts which adversely affect farmlands. This work addresses the desalination of the effluent from WWTPs with a dual purpose: irrigation and the leaching of salts in soils. The desalination of WWTPs effluent has an environmental impact (there will be environmental cost savings related to not spilling salts) and an economic impact (water will be available for irrigation of farmlands). This study assesses the feasibility of desalination in the effluent of a WWTP sample considering the internalization of environmental externalities. Using the shadow prices methodology, the environmental avoided cost of reducing the salinity of the effluent of WWTPs is quantified as 62 € per kg of salt which is reduced. The feasibility study of effluent desalination has been modelled for growing vegetables, taking into account the 272 hectares/year that can be irrigated with the available volume of desalinated effluents. This modelling confirms that the reduction in the effluent's salinity makes it possible to reduce the environmental impact in soils with salinity problems, and also, from an economic point of view, allows farmers to generate an income.

Keywords: Salinity; Distance function; Water reuse; Irrigation; Water quality; Cost-benefit analysis

1. Introduction

The current state of water resources presents a challenge in the management of the available water volume. Two of the main problems with water management are first the lack of water for agricultural irrigation and second the poor quality of the available water resources. Water quality is a key factor since it determines the potential for future use. A factor that has a negative effect on water quality is salinity, which has important environmental and economic consequences. Water salinity affects the soil quality directly, because of reduction in the irrigation uses of this water. For that reason, both water and soil salinity are linked [1]. Worldwide, an estimated 950 million hectares of soil are affected by salinity. The main impacts of salinity on soils are: (i) a reduced production capacity; (ii) less variety of crops because the tolerance of plants to salinity varies between species; (iii) crops need more water to achieve equal development; (iv) in the worst cases the soil becomes unsuitable for agricultural production and the land is finally abandoned [2–4]. These

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impacts mean that salinity is a threat to the soil integrity and the continuation of agriculture [5].

In order to avoid this situation, preventive and corrective measures should be implemented to eliminate the environmental and economic impacts [6]. Salt leaching is the most commonly used corrective measure to reduce soil salinity [7,8]. Increasing the water volume that reaches the soil allows the salts to dissolve and to be eliminated from the root zone of plants [9]. However, leaching of salts is an unviable technique in arid and semi-arid regions, due to the climate (high temperatures, which favour an increase of salts through the evaporation processes) and limited water availability [2]. As a preventive measure, the current trend is to use wastewater treatment plant (WWTP) effluent as a non-conventional water source [10]. There are many countries that use effluent as irrigation water [11–14]. This trend is reasonable because WWTP effluent is a constant and reliable source of water to ensure the sustainable irrigation of farms, reducing the pressure on fresh water sources [1,4,15,16]. The reuse of WWTP effluent for irrigation is widely documented in the literature [17–20]. In the case of the European Union, the main countries using this water source are Spain, Italy, Greece, Cyprus, France and Portugal because they are the countries most influenced by the arid and semi-arid climate [16,21]. In Spain the total wastewater generated by 2014 was 14 million m^3/d, while the volume of wastewater that was reused was only 1.5 million m^3/d [22]. This value is global and does not differentiate between the different uses that can be made of reused water. The difference between the total wastewater generated and the total water reused suggests that there is great potential for the use of Spanish WWTPs effluent as a source of water for irrigation; as suggested in the study by Mizyed [23].

Reusing the WWTPs effluents has a quality problem, which is related to the heterogeneity in raw wastewater composition [24]. Focusing on salinity issue, it is clear that reuse of the effluent is a preventive measure to reduce both the water scarcity problem and salinity of soils. However, wastewater has also high salt concentration, this means that it is necessary to apply measures to guarantee suitable quality of WWTPs effluents. Conventional wastewater treatment technologies focus their efforts on the removal of organic fractions from wastewater through biological treatment systems [25]. However, the salinity is not eliminated because salinity is not a pollutant included in the current legislation. This is the reason why WWTPs lack the technologies for removing salts. High concentrations of salts in WWTPs effluent are a hindrance to their agricultural use. It becomes an additional source of salts for the soil, much of which is already affected by salinity [4]. This combination of factors conspires to increase the environmental impact that had initially been produced by the accumulation of salts in the topsoil [26]. The presence of salt in the wastewater has different origins: seawater intrusion processes in coastal areas, runoff waters from intensive farming, industrial processes whose saline effluents are discharged into the urban sanitation network and the strong evaporation of water under high temperatures [27].

The most effective measure to reduce salinity from wastewater is by installing a reverse osmosis tertiary treatment [16]. In Spain, the desalination of the WWTP effluent for agricultural uses is only 13% of the total wastewater treated at national level [22]. This 13% is a low percentage that should be taken as a starting point to further promote the salinity reduction in WWTPs and the subsequent use of the effluent as a source of irrigation and salts leaching. The study by Cirelli et al. [28] analyses the consequences of irrigating a tomato crop with regenerated water (treated by tertiary treatment) for 2 years. The results show that the microbiological quality of the crop is not altered, since there is no presence of faecal bacteria (*E. coli*). Crop production increased by 20% (compared with tomato crops irrigated with conventional fresh water). The study concludes that, with adequate management of the risks associated with the reuse of wastewater (mainly microbiological and chemical pollution), we are faced with an actually viable means of increasing the water volume available for farm irrigation in high water-stress areas. While it is true that the study did not specify whether the tertiary treatment reduces salinity, these results remain relevant since they demonstrate that improving the wastewater treatment technologies allows the use of regenerated water for irrigation, enhancing crop productivity and minimizing the environmental impact [1,29].

From an agricultural point of view, the salinity in WWTPs effluent has a clear environmental and economic impact, both associated with the additional contribution of salts to the soils that are to be directly irrigated with the effluent. These impacts have a cost, which originates from the salinity. In order to quantify the cost of salinity, it must be taken into account that salinity is a constituent of the wastewater purification process itself, which lacks a market. The way to calculate the monetary value of salinity is to implement methodologies that allow the environmental impact to be expressed in monetary units. One of the options available is the shadow prices methodology. Its methodological basis considers that all production processes generate marketable outputs (called desired outputs), generating, at the same time, by-products (called non-desirable outputs) that lack a market and negatively affect the efficiency of the production process. The most common non-desirable outputs are the pollutants generated in the production process. Using the shadow prices methodology, it is possible to calculate the monetary value of the non-desirable outputs (pollutants) and to include them in the decision-making processes [30].

The WWTPs are considered as productive processes; as it had been done in previous works [31–33]. Under this assumption, the desirable output is represented by the treated wastewater and the non-desirable output is represented by the salinity concentration. The shadow prices represent the avoided cost of reducing the pollutants in WWTP effluents. This avoided cost is interpreted as an estimation of the environmental benefit of reducing the discharge of non-desirable outputs [34]. That is, the shadow prices approach obtains the value that represents the environmental cost (in monetary units) that can be avoided if the salinity of the WWTPs effluent is reduced. The result is interpreted as the environmental benefit of the improvement of reusing water quality whose characteristics are suitable for irrigation and the leaching of salts.

The application of the shadow prices methodology, in relation to environmental issues, is focused mainly on three areas: air and water: (i) Air pollution by CO_2 and SO_2 in order to establish the price of the emission rates of carbon dioxide for companies. This implies a quantification of the impact that environmental regulation has on firms, while it is necessary to technologically improve the production process with the aim of reducing the emissions level, as established in the current legislation [35–41]. (ii) Classic pollutants in wastewaters: suspended solids, BOD, COD, nitrogen and phosphorus. In this context, shadow prices quantify the monetary value of these non-desirable outputs from WWTPs, taking into account that their removal efficiency is not 100% [34,42]. (iii) Emerging pollutants present in urban wastewaters, such as ibuprofen, acetaminophen, naproxen, among others. Their chemical structure hamper their removing and provoke that they have been discharged into water ecosystems [43,44]. To date, the literature reveals that salinity has not been considered as a non-desirable output from the wastewater treatment process.

This study is the first implementation of shadow prices methodology related to salt issues. Its presence in WWTP effluents hinders the reuse of these effluents as irrigation source and leaching of salts (mainly in arid and semi-arid regions). This study has two main aims: (i) assessing the feasibility to desalinate the WWTP effluent for irrigation purposes, mainly in farmlands whose salinity problems affect their crop production; (ii) quantifies the shadow price of salt concentration of the real sample of WWTPs of the Valencian Community (east of Spain). Based on the results obtained, the environmental benefit of reducing salt concentration in WWTPs has been obtained. Hence, the calculation of shadow price of salt act as a proxy of the benefit of reuse treated wastewater for agricultural irrigation. Taking into account that the real use of shadow prices into decision-making processes is not widespread, this study has the secondary aim of modelling a feasibility analysis of technological improvement in WWTPs for reducing salts. For this aim, the environmental externalities have been included through the use of shadow prices results.

2. Methodology

2.1. Cost-benefit analysis

Cost-benefit analysis (CBA) is used to compare the economic feasibility of different measures or proposals. The CBA methodology considers the measure analysed “feasible” when its benefits exceeds its costs [34]. The CBA used in this study continues with the approach followed in other studies such as those by Djukic et al. [45], Hernández-Sancho et al. [46], Garrido-Barseba et al. [47] and Molinos-Senante et al. [42,48]. The methodology considers the net profit of each option is the difference between benefits and costs:

$$\mathrm{NP} = \sum B_i - \sum C_i \quad (1)$$

where NP is the net profit; B_i is the value of the benefit item i and C_i is the value of the cost item i [34]. When NP > 0 the measure is economically viable, by contrast, when NP < 0 the measure is not viable in economic terms [49]. Under CBA approach both costs and benefits need to be expressed in present value. It means that net present value (NPV) of a measure is a function of the NP and the discount rate chosen (Eq. (2)). With the discount rate, the investment becomes indifferent regarding cash amounts received at different points of time [50].

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{\mathrm{NP}_t}{\left(1+d\right)^t} \quad (2)$$

where NPV is the net present value; NP_t is the net profit at time t; d is the discount rate and, t is the time horizon of the project. According to the WWTPs approach, NP > 0 means that the benefits of the measure exceed the implementation and operation costs. Hence, the wastewater treatment is a suitable process not only from an economical point of view but also from an environmental point of view [34]. Quantification of the economic costs and benefits it is straightforward because are monitored by WWTPs' managers (investments, operation and maintenance, replacements, among others). However, the quantification (in monetary units) of the environmental costs and benefits is complex. These environmental costs and benefits lack of market; but, taking into account the Water Framework Directive, environment must be considered in the feasibility assessment of those measures related to wastewater treatment improvements [50]. One of the options available to quantify environmental aspects of WWTPs is the shadow prices methodology. As mentioned above, with shadow prices can be quantify the environmental benefit of reducing the discharge of non-desirable outputs. Hence, results are interpreted as the environmental benefit of the reduction in salts concentration, allowing the reuse of WWTP effluent for irrigation and leaching of salts.

2.1.1. Cost of wastewater treatment process

The costs of wastewater treatment process have been obtained thanks to the Regional Wastewater Authority of Valencian Community. Four inputs have been considered: energy, staff reactive and maintenance and waste management, expressed in €/year (Table 1). These inputs are interpreted as a proxy of the total cost of the wastewater treatment process. The energy costs include both the fixed and variable parts of the energy consumption of the WWTPs. Staff costs are comprised by wages, social security charges, taxes, and social insurance. Reagent and maintenance costs include the costs of reagents required for the treatment of wastewater and sludge. Furthermore, the maintenance costs include the equipment and machinery maintenance and replacement. Finally, the waste management costs are related to sludge and wastes of primary treatment disposal.

2.1.2. Environmental benefit (shadow prices)

The economic value of salts in WWTP effluents is complex because it is not quantification by the market. The quantification of environmental benefits of salts (considering as non-desirable outputs) has been made by the shadow price methodology. The WWTPs are considered as productive processes; as it had been done in previous works [31–33]. Under this assumption, the desirable output is represented by the treated wastewater and the non-desirable output is represented by the salinity concentration. The shadow prices methodology results in the avoided cost associated with reducing the pollutants. This avoided cost is interpreted as an estimation of the environmental benefit (in monetary terms) of reducing the discharge of non-desirable outputs [34]. The result is interpreted as the environmental benefit of the improved water quality (reducing salts concentration) whose characteristics are suitable for irrigation and the leaching of salts.

This study has been based on the approach of Färe et al. [51], which is based on the concept of distance functions. Distance functions measure the difference between the efficiency of a WWTP (output produced) and the outputs of the more efficient process [34,43]. That is, this methodology seeks to maximise the production of the desired outputs and at the same time to avoid the generation of non-desirable output [37], in the context of available technology [46]. The distance function is defined as:

$$D_0(x,u) = \inf\left\{\theta : \left(\frac{u}{\theta}\right) \in P(x)\right\} \tag{3}$$

where $x \in \Re_+^N$ represents a set of inputs ($X = (x_1,\ldots,x_N)$), $u \in \Re_+^M$ represents a set of outputs ($U = (u_1,\ldots,u_M)$), being x_n and u_m the amount of input n and output m utilized and produced by the WWTP, respectively (n: 1,…,N and m: 1,…,M). In addition, $P(x)$ represents a production set, which is defined as $P(x) = \{u \in \Re_+^M : x \text{ can produce } u\}$. High values of D_0 means high efficiency, since the WWTP analysed are close to the frontier [34]. The distance function is estimated through optimization of a translog function [51]:

$$\begin{aligned}\ln D_0(x,u) = {} & \alpha_0 + \sum_{m=1}^{M}\alpha_m \ln u_m + \sum_{n=1}^{N}\beta_n \ln x_n + \\ & \frac{1}{2}\sum_{m=1}^{M}\sum_{m'=1}^{M}\alpha_{mm'}(\ln u_m)(\ln u_{m'}) + \\ & \frac{1}{2}\sum_{n=1}^{N}\sum_{n'=1}^{N}\beta_{nn'}(\ln x_n)(\ln x_{n'}) + \sum_{n=1}^{N}\sum_{m=1}^{M}\gamma_{nm}(\ln x_n)(\ln u_m)\end{aligned} \tag{4}$$

Linear programming is used to estimate parameters (α,β,γ) of the distance function:

$$\text{Max}\sum_{k=1}^{K}\left[\ln D_0\left(x^k,u^k\right)\right] - \ln(1) \tag{5}$$

subject to:

$$\ln D_0\left(x^k,u^k\right) \le 0,\ \forall k = 1,\ldots,K \tag{6}$$

$$\frac{\partial \ln D_0\left(x^k,u^k\right)}{\partial \ln u_m^k} \ge 0, \qquad \forall k = 1,\ldots,K.;\ \forall m = 1,\ldots,i. \tag{7}$$

$$\frac{\partial \ln D_0\left(x^k,u^k\right)}{\partial \ln u_m^k} \le 0, \qquad \forall k = 1,\ldots,K.;\ \forall m = i+1,\ldots,M. \tag{8}$$

$$\sum_{m=1}^{M}\alpha_m = 1\sum_{m'=1}^{M}\alpha_{m\,m'} = \sum_{m=1}^{M}\gamma_{n\,m} = 0,\ \forall n = 1,\ldots,N.;\ \forall m = 1,\ldots,M. \tag{9}$$

$$\begin{aligned}&\alpha_{mm'} = \alpha_{m'm}, \qquad \forall m = 1,\ldots,M; \qquad \forall m, = 1,\ldots,M;\\ &\beta_{nn'} = \beta_{n'n}, \forall n = 1,\ldots,N; \qquad \forall n' = 1,\ldots,N\end{aligned} \tag{10}$$

where k = 1,…,K representing the number of production units included in the analysis; being the first i outputs the desirable outputs and the rest (i + 1,…,M) the non-desirable. Despite in Eq. (5) the function $D_0(x,u) \le 1$ has been maximized, its logarithm is equal to or lower than 0. Hence, through the maximization of the function, the minimization of the sum of deviations of each individual unit is obtained. Considering the work of Bellver-Domingo et al. [43], the restrictions are defined as: (i) Eq. (6): each unit has to be placed below or above the production frontier; (ii) Eq. (7): desirable outputs must be positive or zero; (iii) Eq. (8): non-desirable outputs must be negative or null; (iv) Eq. (9): this restriction is used to ensure the free availability of outputs; and (v) Eq. (10): is a restriction that ensures the symmetry of the inputs and outputs.

There is duality relationship between the distance function and the revenue function [52,53], which can be expressed as:

$$R(x,r) = \sup_u\left\{\text{ru} : D_0(x,u) \le 1\right\} \tag{11}$$

$$D_0(x,r) = \sup_u\left\{\text{ru} : \text{R}(x,u) \le 1\right\} \tag{12}$$

where $R(x,u)$ is the revenue function and r represents the output prices. Both functions – functions $D_0(x,u)$ and $R(x,r)$ – are differentiable [52].

Considering all the previous information, shadow prices equation has been obtained (Eq. (8)). It has been assumed that the shadow price of a desired output is the same value as its market price, which is the observed output price of the mth output = r_m where r_m is the mth desired output shadow price. Hence, for all $m \ne m'$ the shadow price formula can be obtained as [51]:

$$r'_m = r_m^0 \frac{\dfrac{\partial D_0(x,u)}{\partial u'_m}}{\dfrac{\partial D_0(x,u)}{\partial u_m}} \tag{13}$$

where r'_m represents the shadow price value, and m is the desired output whose market price is r_m^0.

3. CBA scenario

Taking into account the aims of our study, it has been considered the future scenario where the WWTP effluents are reused for irrigation purposes. All WWTPs analysed – which receive urban wastewaters – have activated sludge treatment and none of them have tertiary treatment, reducing the water quality of effluents. Considering the Spanish Royal Decree 1620/2007, which establishes the regulations applicable to water reuse, the parameters that need to be controlled for water reuse are four: nematodes, *E. coli*, suspended solids and turbidity. However, salinity is not considered, despite the high environmental impact of salts in the effluents. It is necessary to quantify the environmental benefit of reducing the salts in WWTPs. It has been considered 24 WWTPs of the Valencian Community which exceed the salinity criteria of water quality for irrigation established by the Department of Land, Air and Water Resources. The salinity criteria are classified in three groups: (i) low: <0.7 dS/m, (ii) moderate: 0.7–3.0 dS/m and (iii) severe: >3.0 dS/m [54]. The high salinity levels are mainly due to two reasons: on the one hand, uncontrolled industrial discharges into sewage system and, on the other, filtrations in the wastewater collection system especially in areas with a very saline soil. Taking into account that the mean salinity of the sample is 3,340 mS/cm (Table 1), the effluents from the sample WWTPs would not be suitable for irrigation and crop production; if are directly used without treatment – as is shown in Ganjegunte et al. [55]. The mean salinity value of the sample is reflected in kg/year in order to homogenize units for the subsequent CBA. In that case, the mean value of salinity that is discharged to the ecosystem through the WWTP effluents of the sample is 6,519,634 kg/year. An environmental impact would be generated on the receiving soils, which already have existing salinity problems.

In order to show how to implement shadow prices results in a decision-making processes, it has been considered the hypothesis in which there are soils with high salt concentration and low productive capacity. These soils have lost their agricultural production capacity, with negative economic, environmental and social consequences [56]. The reuse of water with low salinity for irrigation these soils would have a double effect: leaching salts and recovering the productive capacity of the soil. Reducing the salinity in WWTPs can be done by installing a tertiary treatment with reverse osmosis (RO). This technology is proposed in order to test the applicability of shadow prices into decision making processes. For future situations, more research is needed in order to select the technology to remove salt. Taking into account the requirements of RO, the use of 100% of permeate is considered; that is, the water volume of desalinated effluent available for irrigation corresponds to 50% of the feed flow on the RO system (Table 1). This flow corresponds to 1,525,146 m^3/year. The volume of desalinated effluent can be considered as a first approximation of the hectares that can be irrigated annually with the regenerated wastewater available. Therefore, the total irrigable surface area could reach 272 ha/year. The flow of brine has been treated properly to avoid environmental problems. Taking into account that this scenario is a simulation, it has been considered that the brine will be discharged into an evaporation pond. This treatment has a low cost for WWTPs managers, because WWTPs analysed are located in a semi-arid coastal region with high solar energy. For the purposes of this study, brine disposal has zero-cost, both implementation and operation [57,58]. In future studies, different brine treatments shall be considered.

As it has been proposed, the reuse of regenerated effluent, it has been considered the cultivation of vegetables (such as artichokes, aubergines, courgettes, onions and tomatoes), based on both their seasonal rotation and their production yield [59]. It is an assumption to serve as a starting point for including shadow prices in a feasibility analysis. For Spanish market, the vegetables production yield is quantified as 17.2 T/ha, with an average selling price of 413 €/T [60]. Seasonal rotation of vegetable cultivation allows farmers to maintain crop productivity throughout the year. An essential aspect to take into account is the irrigation needs of the proposed crop. According to data from the Spanish National Institute of Statistics [61], the typical requirement for vegetables irrigation is 5,606 m^3/ha. Regarding the requirement for fertilizers, the literature quantifies that around 145 kg/ha would be necessary [59]. From this value and the irrigable surface area, the total costs of the use of fertilizers for the maintenance of the vegetables crop are quantified as 31,479 €/year. Another cost considered is the price of the desalinated effluent tariff. According to Molinos-Senante et al.'s [62] study, the reclaimed water prices vary for different countries and purposes. In this case, it has been considered a tariff of 0.5 €/m^3 for desalinated effluent. According to the literature, it should be considered that the production costs of desalinated effluent through RO should be considered as 0.6 €/m^3 [63]. It should be noted that the principle of cost recovery established by the Water Framework Directive is applicable to the value of the desalinated effluent tariff proposed here. In this case, 0.5 €/m^3 would be paid by water users (in this case, farmers), while the remaining amount (to match the production costs of desalinated effluent – 0.1 €/m^3) would be paid by the authorities, as being mainly responsible for the conservation of water bodies and the environment.

As a fundamental part of the cost structure of the use of desalinated effluent for irrigation and leaching of salts, the costs associated with the installation and functioning of an RO treatment after the secondary treatment must be considered [25]. In order to estimate the investment, energy and operation and maintenance costs, we used the cost functions shown in the study by Marcovecchio et al. [64]. These cost functions consider all aspects involved in the installation and operation of the RO (including pre-treatment of wastewater from the secondary treatment). Table 2 shows the average values of vegetables crop production and the application of the cost functions for the analysed sample.

Table 1
Description of WWTPs sample (mean values)

Energy	(€/year)	236,700
Staff		277,697
Reactive and maintenance		144,088
Waste management		65,953
Volume of wastewater treated	m^3/year	3,050,292
Salinity	mS/cm	3,340

4. Results and discussion

4.1. Environmental benefit

As pointed out above there is a relationship between the desirable and non-desirable outputs, hence, to calculate the shadow prices of non-desirable outputs it is necessary to know the market price of the desirable output, that is, the wastewater treated. Taking into account that market price of the treated wastewater is difficult to know because

Table 2
Cost structure of modelling scenario (mean values)

		Units	Value
Vegetables crop	Yield of vegetable cultivation	T/ha	17.2
	Market price of vegetables	€/T	413
	Irrigation requirement	m^3/ha	5,606
	Irrigable surface area available	ha/year	272
	Vegetable production	T/year	4,687
	Fertilizer requirement	kg/ha	145
	Amount of fertilizer required	kg/year	39,497
	Fertilization costs of available surface	€/year	15,740
	Desalinated effluent tariff	€/m^3	0.5
	Income expected from sale of the crop	€/year	1,935,570
RO	Investment cost	€	3,130,248
	Operation and maintenance cost	€/year	499,153
	Energy cost	€/year	28,243
	Water production cost	€/m^3	0.6

does not exist a real market for this output, we have used the referenced price of the treated wastewater provided by Hernández-Sancho et al. [46]. This study shows that market price of the desirable output depends on the discharge area of the WWTP effluent (wetland, river or sea, among others). For obtaining these prices, the authors analysed and compared different wastewater reuse projects promoted by Spanish water authorities; such as Jucar River Basin Authority and Ministry of Environment [31]. Hence, since the results of these projects and taking into account that the WWTP effluents have been reused, the market price for the desirable output has been set at 1.5 €/m^3. The result of shadow prices approach is 62 €/kg (Table 3), which means that for each kg of salt reduced from the effluent, there is an avoided environmental cost of 62 €. The salinity shadow price obtained already suggests a sufficient reason for public authorities to promote technological improvements in WWTPs, which will avoid the environmental impact related to the accumulation of salinity in soils and water.

The non-desirable outputs that have been mainly considered in the WWTPs are solids in suspension, BOD (biological oxygen demand), COD (chemical oxygen demand), nitrogen and phosphorus [31]. The study by Molinos-Senante et al. [42] shows that the shadow price of nitrogen is quantified as 35 €/kg and the shadow price of phosphorus is quantified as 82 €/kg. Comparing these results with the result of the shadow price of salinity (62 €/kg), we can confirm that the result obtained is in line with previous literature and it reflects the relevance of reducing salinity in WWTP effluents.

The shadow price obtained is a proxy of the monetary value of salinity in WWTP effluents. Thus, taking into account the average flow of the sample and the average amount of salinity present in the WWTP, the environmental benefit value is obtained. This environmental benefit is a quantification of the monetary value of the positive externalities that can be obtained if the salinity is reduced. As shown in Table 3, the environmental benefit is represented in million €/year, in relation to the concentration of salinity of the sample. Quantification of the environmental benefit realized from the shadow prices approach is an objective economic valuation, which allows us to include it in the feasibility study. The environmental benefit of reducing the salinity concentration in WWTP effluents is quantified as 403.9 million €/year. Environmental benefit can be interpreted as the environmental relevance of reducing salinity discharging through WWTP effluents. This environmental benefit is the starting point to justify the reuse of effluents for irrigations purposes; highlighting the need for treated wastewater to be of adequate quality before reaching the soils.

Table 3
Shadow prices methodology results and environmental benefit obtained related to salinity reduction in WWTPs effluents

	Units	Value
Shadow price	€/kg	62
Environmental benefit	millions €/year	403.9

4.2. Feasibility analysis

At this point, the feasibility study is presented through a CBA including the values shown in Tables 2 and 3. Through the CBA, the feasibility is evaluated first, from the point of view of WWTPs, which will carry out a technological improvement associated with the installation of the tertiary treatment with RO (Table 4). It is at this point that the shadow price of salinity is included in the analysis as an external benefit. This allows us to internalize environmental externalities within the CBA. The final result of the CBA (from the WWTPs point of view) will take into account the avoided environmental cost of reducing the salinity of WWTPs effluents. In order to demonstrate the difference between the internalization of environmental externalities and their non-internalization, the modelling of the CBA scenario from the point of view of the WWTP includes the NPV when the environmental benefit is not taken into account. Second, the feasibility is evaluated from the point of view of the farmer. The costs and benefits associated with the cultivation of vegetables in 272 ha are analysed. In this scenario, accounting costs and benefits are considered, because the farmer only has to maintain the vegetable production. The CBA only takes into account the costs associated with fertilizers, the payment of the desalinated effluent tariff, and the benefits obtained from the sale of the vegetable crop. From both points of view (WWTP and farmer), a 25 year useful life has been considered (since this is the useful life of the RO technology), with inflation of 2%, a discount rate of 3.5% and an interest rate of 2%. The results of NPV (obtained according to Eq. (2)) for both points of view are presented in Table 4.

The case of the NPV of the WWTPs is relevant. The strict accounting analysis of the costs and benefits of RO shows that the NPV obtained would be negative (–23,255 M€), because the investment and maintenance costs of RO would outweigh the benefits that would be obtained through the desalinated effluent tariff. However, the internalization of environmental externalities through the shadow prices methodology reverses the situation, and the NPV obtained is positive (12,242 M€). Internalization of the environmental externalities is a current trend that is being taken into account because the measures to be implemented (RO) will achieve a reduction of the current environmental impact (leaching of salts into the soil). It is coherent to consider the environmental benefit as a fundamental part of the CBA, making real the theory of the internalization of environmental externalities. The use of the shadow prices methodology allows us to obtain an objective value (through mathematical optimization processes) that provides a robustness to the analysis and goes one step further than the classical methodologies of the economic valuation of environmental goods and services (such as contingent valuation or hedonic pricing).

The CBA results from the farmer's point of view correspond to a classical CBA, whereby farmers can assess the suitability of using the desalinated effluent for irrigation, taking into account the desalinated effluent tariff and comparing it with the benefits they will obtain from the sale of their vegetables crop. Therefore, the possibility of cultivating 272 ha annually results in an NPV of 28.9 M€. In this situation, it is feasible to use the desalinated effluent to irrigate the vegetable crops (where the salts accumulated in the soil will be leached). The costs incurred by farmers (fertilization and desalinated effluent tariff) are less than the benefit associated with the sale of the vegetable crop.

This study sheds light on the quantification of the environmental benefit in monetary units of salinity; which could be included in decision-making processes regarding technological improvements of WWTPs. Specifically, the shadow price methodology is a way to calculate the monetary value of environmental externalities which lack of market value, with lower implementation costs in comparison with other methodologies, such as contingent valuation [43]. Shadow prices provide decision makers with estimates of the environmental costs of having high salinity concentration in WWTP effluents. The novelty of this study is to consider salinity as environmental externality of wastewater

Table 4
Results of NPV for the both points of view analysed

	NPV (M€)
CBA of RO (including environmental externalities)	12,242
CBA of RO (without environmental externalities)	–23,255
CBA from farmer's point of view	28.9

M€: millions of €.

treatment process, hindering the reuse of this water for irrigation purposes. From a holistic point of view, environmental externalities need to be vertically and horizontally integrated within environmental policies; without forgetting the relevance of presence of farmers within that process [65]. Therefore, economic valuation of environmental externalities can be integrated into governance processes; whose institutions encourage interaction among political and social actors to manage their interests with respect to agricultural exploitation, so that decisions will be taken to achieve long-term soil productivity [66].

Economic value of salinity has been included within feasibility analyses, specifically in CBA, to assess the feasibility of technological improvement in the WWTPs analysed (RO system). This CBA modelling is in the line of other studies, such as Bark et al. [67] and Busch et al. [68]. The results of CBA will help the decision-maker in the design of technological improvements in those WWTPs whose effluent has been reused for irrigation purposes, thanks to the internalization of environmental externalities. The obtained shadow prices follow the trend of the literature findings in quality issues and demonstrate that the shadow price methodology is able to quantify the environmental benefit of removing salts from WWTP effluents [43].

5. Conclusions

The shadow price value is interpreted as the environmental benefit of reducing pollution in effluents. Hence, an effluent with low salinity value provokes an environmental benefit which could be quantified through this methodology. Result obtained here and the volume of effluent available has been used to model how much land can be put into agricultural production, considering the cultivation of vegetables and their irrigation requirements under wastewater reuse approach. The hypothesis analysed considers that it is necessary to reduce the salinity of the WWTPs effluents for reuse it for irrigation purposes and leaching salts. From an economic point of view, the reduction in salinity represents an environmental avoided cost for the ecosystem. The quantification of this cost through the shadow prices methodology has allowed us to establish that for each kg of salts that is reduced in effluent, the avoided environmental damage cost is 62 €. This result is obtained through a mathematical optimization procedure that uses the salinity data derived from the quality monitoring of the WWTPs analysed. The relevance of this work resides in the fact that salinity is a non-desirable output of the WWTPs, which must be reduced in order to maximize the quality of the effluent and its future uses. This is the first time in the literature that the methodology of shadow prices has been applied to salinity data. The objectivity of the result has been ratified, and its suitability to be included in the decision-making processes has been proved.

The novelty of this study highlights that the shadow prices methodology allows to quantify economically the impact that the salinity of WWTPs effluent has on the ecosystem. Furthermore, it has been modelled a scenario – through CBA approach – in which desalinated effluent would be used for both salt leaching (solving the problems of water availability for this technique) and irrigation (allowing the irrigation of 272 hectares and their cultivation with vegetable crops). This methodology means a clear advantage in the economic quantification of the environmental impact of non-desirable outputs (environmental externalities) that are discharged to ecosystems (such as agricultural soils) through the WWTPs effluent, which clearly harm the options of reuse of these effluents. Therefore, monetary valuation of environmental externalities can be integrated into decision-making processes; whose institutions encourage interaction among political and social actors to manage their interests with respect to agricultural exploitation and water resource management.

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