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Social and private costs of water for irrigation: The small desalination plant in San Vicente del Raspeig, Spain

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1. Introduction

Water scarcity is one of today's most important challenges and constitutes an increasing problem in many parts of the world [1,2]. Around 70% of the world's available resources are estimated to be used for irrigation, which can rise even more in some countries and regions, and exceed 90% [3]. In order to address such increasing water scarcity, alternative water sources for irrigation purposes need to be developed, particularly in arid and semi-arid areas. Among non-conventional water resources, desalination (from seawater or brackish aquifers) has emerged as a feasible option to increase water resources availability. It has also become an extensively applied and sustainable solution for an increasing number of regions worldwide to solve water scarcity problems [4–6].

Furthermore, as the cost of desalination has progressively dropped over the years and conventional water resources have not become easily accessible in many worldwide regions, desalination is now more economically competitive and attractive [7]. This fact has also led to some saline/brackish continental aquifers in south European Mediterranean countries being exploited [8,9].

Economic evaluation project techniques are frequently used to assess desalinated water prices [10]. However, to estimate the full cost of water estimations, it is necessary to include not only supply costs (operation, maintenance, and capital costs), but also other environmental and social costs (e.g. use for landscape irrigation), which are not generally taken into account.

Green areas and urban parks provide significant socio-economic, environmental and health benefits to city residents, and contribute to the quality of life in the urban setting [11,12]. Although an extensive literature assigns green areas and urban spaces for market value valuations based on different techniques and procedures [13–15], the public's "parks and gardens" assets are difficult to evaluate. The most commonly used valuation methods are: travel cost, hedonic prices and contingent valuation. The appeal of these techniques is that they facilitate the construction of a market in which researchers can observe an economic decision directly related to the asset in question [16]. The willingness to pay (WTP) approach for preserving green areas, based on a contingent valuation method (CVM), is a widely used accepted method used to collect data from respondents in their area of expertise. The main feature is that the individual is left only with the problem of deciding if (s) he is willing to pay a fixed sum to access the benefits of the park, lagoon, green area, etc. offered [17–20].

At San Vicente del Raspeig in SE Spain, where the University of Alicante (UA) is located, water is a limiting resource. Its low groundwater quality for irrigation, together with new developments in desalination, motivated the UA to build a small RO desalination plant (450 m^3/day) to ensure water availability for its green areas, urban park and a lagoon used for desalinated water storage [21]. The aim of this research was to calculate the real value of the desalinated water used on the campus by estimating the monetary benefits that arise from the UA's green area irrigation, lagoon and urban park maintenance, and to evaluate the impact on citizens' WTP to preserve it.

For this research, a methodological framework for the private cost calculation of the small RO desalination plant was firstly obtained; secondly, a contingent valuation method, (CVM), using a Delphi methodology based on a questionnaire approach, indicated the hypothetical maximum WTP to preserve the lagoon, the green area and the park used.

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2. Study area

This study focused on the San Vicente del Raspeig area (Alicante, SE Spain; Fig. 1). Characterised by a semi-arid climate and low precipitation (300 mm/y), rainfall is most irregular, and half the annual precipitation can easily be obtained in just a few hours [8]. This area has had severe drought problems in recent years.

The UA campus covers approximately 30,000 m^2 of irrigated garden areas with lawn, ornamental plants and trees. This area, and especially the urban park, has had a socio-economic and environmental impact on the zone. Faced with a growing campus and water needs, and having to consider water scarcity, a solution was sought by the RO desalination project of continental brackish groundwater from the underlying quaternary aquifer. Presently, the landscape is irrigated with a mixture of desalinated brackish groundwater and raw water from the aquifer [21].

Aquifer matter comprises silty sandy materials with some clays overlying the impervious loam materials of Cretacic origin. The geology of the region is rather complex, which includes the presence of some outcrops of gypsum, which lead to poor groundwater quality. Electric conductivity values above 6000 μS, and SO^4, Cl and Na concentration of around 1800 mg/l, 1500 mg/l, and 1200 mg/l, respectively, are quite common.

Between 1997 and 2014, the plant has replaced 1,900,000 m^3 of drinking water by desalinated water and brackish well water. The facility has led to significant economic savings and has allowed the use of water resources that were previously unusable due to the high natural salinity.

2.1. The University of Alicante brackish water desalination plant

Initially set up for academic purposes, the RO plant is fed with water from a 33 m deep well pumping the brackish aquifer. Desalted water is conveyed to a pond where is stored and blended with raw groundwater from a second aquifer pumping well located in campus. The proportion of groundwater and desalted water mix ranges between 5% for winter and 22% during summer. Rejected brines are conveyed to an ephemeral creek.

Initial design of treatment capacity was 450 m^3day and 72% of conversion capacity. Currently, the desalination plant produces 351 m^3/day of permeate, and 63% of conversion. There is a single treatment line with a total of 25 membranes distributed in two stages (15 membranes in the first stage and 10 in the second). The membranes used are spiral-wound, aromatic polyamides arranged in modules supplied by Hydranautics (8040~UHY-ESPA). The working pressure is 12 kg/cm^2. It is important to point out that there is a variable frequency incorporated into the plant that controls the operation of the high-pressure pump.

The pre-treatment consists of a filtration system with sand filters and cartridge filters, with a continuous application of 3.8 mg L^{-1} PERMATREAT191 antiscalant, and finally the water produced is conveyed to an accumulation deposit with a capacity of 500 m^3. After desalination and $Ca(OH)^2$ addition for a pH increase, water is finally stored in the accumulation deposit (pond) with a capacity of 500 m^3 prior to being used in campus irrigation. For an extensive information regarding the facility, the reader is submitted to [22,23].

3. Data and methods

The followed procedure was based on the collected data and included two steps: private cost calculation of desalinated water and applying the contingent valuation method (CVM) to the obtained cost to assess the final price.

The amount of irrigation water applied to green areas and the park, 148,500 m^3/yr, was provided by the personnel in charge of the operational UA desalination plant.

For social data collection purposes, no face-to-face interviews were conducted. Instead 40 questionnaires, followed by telephone interviews, were sent by Email to selected residents and to UA personnel (known as a panel of experts) in spring 2017. The questionnaires were based on the Delphi technique [24].

The Delphi technique, a consensus-building tool, is a widely applied methodology for identifying and particularly prioritizing issues in problems that are complex and require intuitive interpretation of group opinion [25,26]. A Delphi methodology involves three steps: Firstly, the process begins with an open-ended questionnaire soliciting information to participants panel; the collected information is converted into a well-structured questionnaire. Secondly, each Delphi participant receives a second questionnaire, and issues of disagreement and agreement are identified by the researcher. Thirdly, the issues are rated by the panel providing individual scores for defined items.

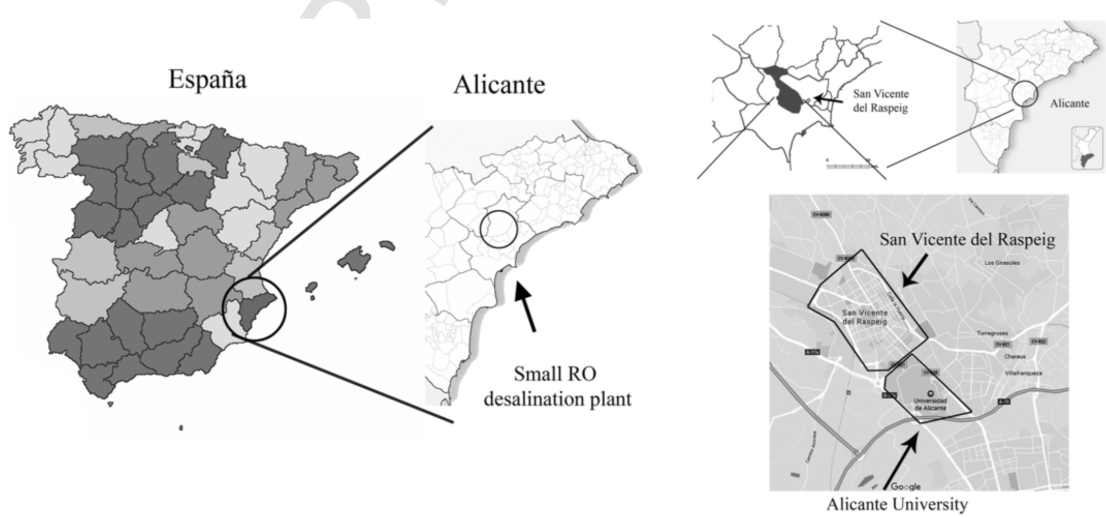

Fig. 1. Study area and the park's location.

3.1. Private cost calculations

The factors to determine the private desalinated water production cost included both fixed and variable costs (see Table 1). For the studied desalination plant (14–20 m^3/h), data were provided by the Plant Manager.

Investment costs included, constructing the desalination plant (for a 25-year life span), civil works on wells, electromechanical equipment and building the pond. The applied depreciation rate was 4%, a common value for such projects [9,27,28].

The parameters for the variable cost estimations were: P) Personnel, covered by one part-time person, considered 30% of salary; M) Maintenance, the cost of the mechanical and electrical equipment, estimated on 1% of the total investment value of the installation based on the plant's level of maintenance and the high-quality building materials; R) Replacing membranes, the present cost of a membrane is €600 (year 2017). It was carried out by assuming an annual rate of 5–10% of the total cost of the membranes to be replaced and the lifetime of the membranes; FCR) Replacing filter cartridges: three sets of cartridges are needed for 1 year, where each cartridge costs €12/; CP) chemical products, needed to condition the input water (permeate) and to clean membranes; E) Energy, to calculate the cost of energy, it is necessary to know the volume of energy per unit volume of water produced in the different process phases (pumping, process and transport to the pond), expressed as kWh/m^3, the cost of electricity per kWh used and the electricity market price expressed as €/kWh.

3.2. The user's willingness to pay (WTP) and the contingent valuation method (CVM)

To estimate the WTP for the green area, the lagoon and the park, the CVM, based on a defined questionnaire with a Delphi technique, was adopted. The contingent valuation method (CVM) is a survey-based approach used to place a monetary value on public and environmental assets not routinely bought and sold on the marketplace [29,30].

The questionnaire consists of five main sections that refer to: *i)* how to go to the urban park (distance, residence, time to get there); *ii)* use of urban park facilities and the activities likely to be enjoyed during free time; *iii*) views on the lagoon's environmental biodiversity and water quality; *iv)* a poll 'for' or 'against' applying an annual environmental tax of: €10 (minimum value required for park maintenance), €15, €20 or €25; *v)* personal and socio-economic questions of respondents: age, gender, family income, schooling, children and house location. Selected factors for the WTP assessment are shown in Table 2.

The WTP (€) estimation per visitor was based in the analysis of the answers provided by the 40 selected residents at annual rate. The green area, lagoon and urban park form an open area for which an inventory of visitors does not exist. For this study, an average of 5600 visitors to the park and lagoon throughout the year was considered, based on the assumption that only 10% of the nearby population of San Vicente del Raspeig (56,700 inhabitants) enjoys the area.

To obtain the WTP, the utility (U_q) and marginal utility ($U\Delta$) function parameters should be firstly estimated. The utility function, which defines individual preferences of users or if someone prefers a specific tax value, depends only on tax amount and is considered the only determinant factor [31–33]:

$$U_q = \alpha_0 + \beta_y + \varepsilon_0 \tag{1}$$

where α is a constant value that acts as a coefficient of the dependent variable (β_y, proposed tax amount) and ε_0 is a random term. The marginal utility refers to the visitor willingness to pay, and based on the theory we obtained:

$$U\Delta = \alpha_0 - \beta\,(Z0) \tag{2}$$

where Z0 = 1: if I agree to pay, and if I do not agree to pay: Z0 = 0.

The maximum likelihood method [34] was applied to estimate function parameters "α" and "β". Having obtained the estimates of the model parameters, the next step was to estimate the WTP, and the WTP mean was estimated as:

$$WTP_{(\text{taxes},€)} = \frac{\alpha}{\beta} \tag{3}$$

Other variables may also influence the respondents' WTP. Therefore, a regression model that included social factors was done to assess citizens' availability to visit the park and lagoon. The selection of the important social factors was based on a literature search and on knowledge of the area.

By taking social factors as an independent variable, the equation would be as follows:

$$WTP_2 \quad = F(\,A1, A2, A3, A4, A5) \tag{4}$$

Table 1
The fixed and variable cost parameters for water price estimations.

Fixed costs	
a) Initial investment: $I = (A)$	I = initial investment A = cost of the desalination plant
b) Amortisation: $a = I \bullet \frac{i\bullet(1+i)^n}{i\bullet(1+i)^n-1}$	I = investment n = number of lifetime years of the investment i = interest
Variable costs	
d) Operational and maintenance costs: CE $CE = P + M + MR + FCR + CP + E$	P = personnel M = maintenance MR = replacing membranes FCR = replacing filter cartridges CP = chemical products E = energy cost

Table 2
Description of the factors that influence the WTP and respondents' availability to visit the park and lagoon.

Factor	Value
Tax amount (€)	(1) 10, (2) 15, (3) 20, (4) 25
Income (€/month)	(1) Less than 500, (2) 500–1000, (3) 1000–1500 (4) 1500–2000, (5) 2000–2500, (6) 2500–3000, (7) more than 3000, (8) No answer
House ownership	(1) Home owner, (2) Rent, (3) Staying with a relative/ other
Number of children	(1) One, (2), two, (3), three
Gender	(1) female, (2) male
Leisure time with family and friends	(1) not important, (2) somewhat important, (3) important, (4) very important
Pleasant journey	(1) not important, (2) somewhat important, (3) important, (4) very important

where: A1 (income), A2 (pleasant journey), A3 (leisure time with family and friends), A4 (children), A5 (gender).

For the estimations, the regression Probit model [35] was applied. All the estimations were obtained with the IBM SPSS Statistics 24.0 and Econometric Views 9.1 packages.

4. Results and discussion

This section presents and discusses the produced water cost and the WTP for the case study by taking into account the different obtained values.

4.1. Private cost per m^3 for the small UA desalination plant

Annual private cost of water production (fixed and variable) from obtained information at the plant facility is presented in Tables 3 and 4. The total private cost is the sum of the investment/capital costs (amortisation annuities) and the variable costs, and the summary is in Table 5. All calculations (fixed and variables) are based in the production of 148,500 m^3 of desalinated water during 330 days in a year.

It is important to notice that cost of the UA plant built in 1997 was 60 million pesetas (€360,000). According to the literature and for this type of small desalination plants, cost ranges between €60,500–72,600 + VAT for 2016 [9]. Obtained total fixed cost refers to a 25-year amortisation period at a 4% interest rate and accounts for 0.179 (€/m^3).

Among the variable costs, we obtained an average cost of 0.062 €/m^3 for the UA technical personnel in charge of the plant. The use of chemical reagents for the water treatment is proportional to the produced permeate (m^3) and the dose applied is variable, depending on the water chemical characteristics. From data, the chemical reagents cost is 0.0068 €/m^3. The filter cartridge cost was €12/set and three sets were replaced per year.

Table 3
Estimation of fixed costs (€) for the small UA desalination plant.

Investment + VAT	Amortisation (annuity)	Maintenance[a] (annuity)
360,000	23,044	3600

[a] Estimated as 1% of the initial investment plant.

Table 4
Variable costs estimation for membranes, filters and energy for the small UA desalination plant.

Membranes				
Investment	Total membranes	Replacement cost (10% I[a])		Total cost
(€/Memb.)	(No.)	(€)		(€/m^3)
15,000	25	1500		0.010
Filter cartridges				
Cartridges	Change per year	Cartridge cost	Annual cost	Total costs
(No.)	(No.)	(€)	(€)	(€/m^3)
8	24	12	288	0.0020
Energy cost at uptake				
Pumping depth	kWh/^{3} used	Energy price		Total cost
(m)	(kWh/m^3)	(€)		(€/m^3)
30	0.08	0.04		0.0032
Energy cost for the RO process				
Energy use/day				Total costs
(kW/m^3)				(€/m^3)
450				0.04

[a] Initial investment in membranes.

Table 5
Summary of the total private cost of m^3 for the UA plant.

Plant production (m^3/day)	450
Investment cost (€)	360,000
Amortisation (€/m^3)	0.155
Personnel (€/m^3)	0.062
Maintenance (€/m^3)	0.024
Replacing membranes (€/m^3)	0.01
Replacing filter cartridges (€/m^3)	0.002
Chemical reagents (€/m^3)	0.0068
Energy (€/m^3)	0.04
Total private cost per m^3 (€)	0.2998

The total energy cost of the plant depends on the energy use (kWh/m^3) for the following processes: a) brackish groundwater pumping volume from the well; b) the RO process itself; c) pumping to transport water after desalination to the pond. For this study, an average price of the electricity market of 0.04 €/kW was established. For the groundwater pumping cost estimation, the average value considered was 1 kWh of use per 20 m of pumped elevation. At the UA, the pumping elevation in the well were brackish water is obtained is around 30 m, being considered as an average along the year.

Considering all energy processes, the RO process requires the highest consumption. Due to the amount of dissolved salt in the groundwater (6000 μS/cm of electric conductivity), a lower osmotic pressure is required with an energy use of 1 kWh/m^3. The estimated energy use for water transport to the lagoon required is 0.08 kWh/m^3.

Once considered all fixed and variable costs estimation, the obtained final amount of the total private cost for the brackish plant is 0.299 €/m^3. Due to the UA plant's building age (1997), its cost is slightly higher than those built in recent years, this fact has a direct impact on the final price of desalted m^3.

4.2. The CVM results and WTP model parameters estimates

The results obtained from the questionnaires on the respondents' socio-economic analysis, summarising the demographic and socio-economic characteristics of urban park visitors, are shown in Table 6. According to the outputs (Table 7), leisure time with family and friends is considered the most important activity for visitors. Generally, the UA Park is perceived to be in good condition with areas for jogging, a beautiful garden and a lagoon that motivates visits.

Among the respondent's answers, 20% were against contributing to maintain the park as they argued that it was the University's obligation. For the rest, it was perceived that the park is an interesting location for recreational activities. The majority agreed to pay an annual contribution according to the proposed taxes to maintain the green area, the lagoon and the park. Regardless of how the respondents voted, awareness of urban park importance was perceived by most users as no green areas around the main population of San Vicente del Raspeig exist or long distances must be travelled for leisure.

Table 8 shows the results of estimated WTP model parameters based only on tax prices (Eqs. (1) and (2)). The tax variable (β) was significant, and the negative value of coefficient was consistent with the economic expectations. Thus the higher the tax price, the less likely the respondents would be willing to pay.

Table 6
Respondents' socio-economic characteristics.

Socio-economic characteristics	Frequency (n = 40)	%
Age (yr)		
22–30	14	35.0
31–39	8	20.0
40–48	13	32.5
More than 48	5	12.5
Gender		
Female	22	55.0
Male	18	45.0
Education		
Technical education & lower degree	12	30.0
Bachelor & higher degree	28	70.0
Civil status		
Single	18	45.0
Married	20	50.0
Widowed/divorced	2	5.0
Number of children		
0	15	37.5
1	8	20.0
2	13	32.5
3	4	10.0
House ownership		
Home owner	27	67.5
Rent	8	20.0
Stay with a relative	5	12.5
Monthly income (€)		
Less than 500	2	5.0
Between 500–1000	2	5.0
Between 1000–1500	24	60.0
Between 1500–2000	7	17.5
No answer	5	12.5

Table 7
Importance of the activities carried out at the park.

Activity	No important	Somewhat important	Important	Very important
View of the lagoon (%)	15	25	47.5	12.5
Observing its life span (%)	5	47	45	2.5
Leisure time with family and friends (%)	7.5	22	20	50
Sharing the park's vegetation (%)	5	2.5	52.5	40
Cycling or practicing other sports (%)	7.5	17.5	42.5	32

Table 8
The WTP model parameter values when considering only taxes.

Variable	WTP	t-ratio	p-Value
α	0.068	3.319	0.002
β	−0.005	−9.863	0.000

From Eq. (3) and substituting the α, β estimates, the obtained WTP was 13.6. Residents (a visitor) were willing to pay €13.6 €/yr for the UA park, green area and lagoon maintenance and a total of 76,160 €/year, after considering 10% of the total population who visited the leisure area (the total number of visitors received was 5600).

As for the selected variables influencing WTP, Table 9 presents the regression results regarding social factors that most influenced the respondents' visits to the leisure area (Eq. (4)).

According to the p and t values, the results were statistically significant. The negative "income" value indicated a lower probability of the respondents visiting the park and the lagoon for higher income levels and, therefore, less WTP. The statistical result inferred that people with a low-middle income level enjoyed the benefits of the leisure area more.

Number of children positively influenced the result as the more children the respondents had, the more willing they would be to visit the park as they thought it was a good entertainment place, mainly during holidays.

4.3. *Total social and private final cost*

Considering the estimated 0.29 €/m^3 for the private cost of the desalination plant (Table 5) and the amount of water applied for irrigation following plant needs (148,500 m^3/year), the total production cost of plant accounts for 43,065 €/year. The obtained WTP was 76,160 €/year resulting from multiplying the WTP value (13.6 €/yr) by the number of possible visitors (5600), by considering 10% of the total population in the surrounding area.

The obtained WTP (76,160 €), divided by the amount of annual production of the desalination plant (148,500 m^3), gives the final price per cubic meter 0.51 €/m^3 which includes the benefits generated from the leisure areas for visitors.

5. Conclusions

Traditionally, the economic-financial analysis of the desalination plant focuses exclusively on costs and private benefits. Very few papers that deal with calculating the benefits made by green areas in an urban space have been published. It is quite likely that no research has globally addressed the valuation of a recreational system of an urban park irrigated with brackish water in the way it was performed herein.

The main interest of this research was that all the costs and benefits (social and private) related to a leisure area were considered in an economic analysis by applying the CVM to investigate the WTP that affects the final price for the sustainable development and maintenance of an urban park using brackish water. Given the existing scientific contributions to the subject, the best evaluation method to estimate the benefits made by using the green area, the lagoon and the urban park at San Vicente del Raspeig is the CVM. This is because it is the only technique capable of capturing all the values generated by an environmental attribute, both use and non-use, and does not have the methodological limitations of other methods, such as travel cost (TC), whereas none serves to estimate non-use values. The Delphi technique was a particu-

Table 9
The parameter estimates of the regression model.

Factors	Coefficient	t-ratio	p-Value
Income	−0.872894	−3.819337	0.0001
Pleasant journey	1.799029	6.914081	0.0000
Leisure time	0.335834	4.941514	0.0000
Children	0.200848	2.508848	0.0121
Gender	0.303610	1.785075	0.0742

larly useful tool for development group consensus; the anonymity among participants helped in avoiding digressions of the face-to face discussions and obtaining a convergence to a consensus opinion.

According to the obtained results, the final private water cost was 0.29 €/m^3 showing a significant difference after considering intangible social benefits. The social benefits (WTP results) provided by the leisure areas was 0.51 €/m^3. For this case study the final price of the water, 0.22 €/m^3, is obtained by subtracting the benefits generated by the leisure areas (0.51 €/m^3), minus the private cost (0.29 €/m^3), here considered a benefit and not a cost.

Most respondents considered the urban park and lagoon very important areas to relax in during their free time, and a high proportion of them were willing to pay for maintenance. However, the probability of paying varied according to tax prices and their income.

It is noteworthy that the WTP estimates did not depend on the type of water being applied (tap, treated, etc.). Nevertheless, for the study area, the cost of water from the water supply company is 2.55 €/m^3, which is almost 8-fold higher than the desalination final private cost. The obtained desalinated water cost was 0.29 €/m^3, which renders this assessment economically much more feasible. Not all the possible impacts were economically evaluated in this research; e.g., the benefits related to public health, education or improved air quality would increase the final desalinated water price benefits. Nevertheless, this result demonstrates that the green area, the park and the lagoon have both private economic and social benefits for students and the neighbouring population.

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