

## **FEASIBILITY STUDIES FOR WATER REUSE PROJECTS: ECONOMIC VALUATION OF ENVIRONMENTAL BENEFITS.**

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### **ABSTRACT**

Wastewater reuse is emerging as an alternative of great future as it allows increasing the supply of water resources and reduces pollution problems because it prevents the discharge of wastewater into the environment. In recent decades, technological progress in the field of wastewater regeneration have been very important, so much so that today, wastewater reuse project feasibility is currently primarily subject to economic assessment. In spite of this, the economic aspect is perhaps the least addressed in water regeneration and reuse research, since in general only private costs are considered while the external effects (positive and negative) are relegated to a series of statements about the advantages of water reclamation and reuse. So, usually the methodologies used to analyze the economic feasibility of water reuse projects are focused on the internal costs. As a result, the true benefits and cost of many water reuse projects have never been properly evaluated. Therefore, this paper shows a methodology to assess the economic feasibility of a water reuse project taking into account not just the internal impact, but also the external impact. On the other hand, and due to the few contributions in this research area, a quantification in monetary terms of the environmental benefits gained from a water reuse project is made. The assessment is done through the estimation of shadow prices of undesirable outputs resulting from wastewater regeneration. In this way, a useful economic feasibility indicator can be obtained for a water reuse project taking into account both internal and external impacts.

**Key words:** *directional distance function, economic feasibility, environmental benefit, shadow prices, wastewater reuse, wastewater treatment.*

## **1. INTRODUCTION**

Recurrent droughts lived in recent decades have shown that often the water supply is not balanced with demand (Hochstart et al. 2007). Furthermore, more than 70% of the European population is facing water stress problems, being semi-arid coastal and highly urbanized areas which are most affected by this situation (AQUAREC 2006). In addition, global climate change will worsen this situation, especially in southern European countries where greater susceptibility to drought can cause serious environmental, social and economic problems (Bixio et al. 2006).

Thus, wastewater regeneration and reuse is emerging as a great future alternative because it performs two key functions: on the one hand, increases water supply thus lessening the pressure on conventional natural resources, and on the other hand, reduces pollution problem because prevent the discharge of wastewater into the environment.

In recent years, technological progress in the field of wastewater regeneration has been very important, to the point that nowadays, the feasibility of wastewater reuse projects is subject primarily to economic aspects and social acceptance and not so much to the obtaining of an adequate quality effluent. In this sense, have a detail cost analysis is essential to asses the potential of wastewater reuse projects (Asano 1991, 1998, 2007).

Nevertheless, perhaps the economic aspect is the least studied in regeneration and reuse of wastewater research topic, since in general only private costs are consider, while the external effects (positive and negative) are relegated to a series of pronouncements about the advantages of wastewater regeneration and reuse (Seguí 2004).

Despite the difficulties involved in the quantification of externalities, due to the absence of market to regulate their prices, in the context of wastewater reuse there is a growing interest in the monetary valuation of them. An example of this growing interest is found in the work of Godfrey et al. (2009) who carry out a cost benefit analysis (CBA) applied to a greywater reuse system in India. Monetary values of external benefits and costs in terms of environmental and health benefits were derived by using scientific references (North & Griffin, 1993; Hanley & Spash, 1993; Field, 1997; Curry & Weiss, 1993; Hutton & Haller, 2004). These authors use conventional economic methods for valuation like are hedonic valuation and willingness to pay. On the other hand, Seguí et al. (2009) used the technique of the travel cost to determine the environmental benefits

arising from wastewater reuse in the context of a wetland restoration project. Cheng & Wang (2009) propose a net benefit value model for cost-benefit evaluation of reuse projects which is applied in a residential area of China. The benefits relating to the environment are calculated by applying a mathematical equation developed by the Ministry of Environmental Protection of China.

Although many authors consider the conventional methods of economic valuation (hedonic prices, contingent valuation, travel cost, etc) as consolidated techniques because they are supported by numerous empirical applications, in the scientific community (Diamond & Hausman, 1994; Shabman & Stephenson, 2000; Getzner, 2000, among others) there is no unanimous consensus on the validity of these methodologies because there are difficult to implement by the authorities, their high costs, as well as the limitations and slants that have.

In this context and from the pioneering work by Färe et al (1993) and successive developments (Färe & Grosskopf, 1998; Färe et al. 2001 and Färe et al. 2006), a stream of research has been produced within the framework of efficiency studies that aims to provide a valuation methodology for those undesirable outputs that have no market. Using the concept of directional distance function, a shadow price is calculated for those goods arising from human and productive activities which have no market value and have substantial environmental impacts.

The advantages of this externalities valuation methodology include the following: (i) shadow prices could be used to determine income gained in case of privatization of some resources, (ii) authorities can use the information provided by the shadow prices to set rates for the use of environmental services, or to compare the currently rates with the marginal revenue generating (Färe et al. 2001), (iii) can help society to understand the benefits generated as a result of environmental improvement programs and (iv) shadow price models can allow economists a further check into estimated measures of willingness to pay from alternative models such as the CVM, or capitalization methods (Färe et al. 2001). Shadow prices quantification has very low costs in comparison to always expensive surveying processes.

This work aims to show a methodology to assess the economic feasibility of wastewater reuse projects where not only internal but also external impacts are considered and

quantify, through an empirical application, the monetary value of environmental benefits arising from water reuse. This economic valuation is made by the estimation of shadow prices for undesirable outputs resulting from wastewater regeneration.

## 2. METHODOLOGY

The economic feasibility studies of wastewater reuse projects must be made using conventional methodologies own economic analysis. So the objective is still to maximize the total benefits derived from the project.

According to Seguí (2004) and Hernández et al. (2006), the total benefit is calculated by considering the internal benefit, the external benefit and opportunity cost. The function to maximize takes the following form:

$$MaxB_T = B_I + B_E - OC \quad (1)$$

Where  $B_T$  is the total benefit (total income – total costs),  $B_I$  is the internal benefit (internal income – internal costs),  $B_E$  is the external benefit (positive externalities – negative externalities) and  $OC$  is the opportunity cost.

### 2.1 Internal benefit

The internal impacts are those directly linked with the process of wastewater regeneration and later reuse. The internal benefit is the difference between internal incomes and internal costs. Internal income includes revenues as a result of the sale of regenerated water and other recovered sub-products. If the reclaimed water will be used in agriculture, nitrogen and phosphorus content in this water will be a saving in fertilizer costs, whereas if the reclaimed water intended for environmental purposes, during wastewater treatment it can be recovery these nutrients and then be sold for other uses. Internal costs are the result of the sum of the investment costs (land, civil works, machinery and equipment, facilities and piping works), operating and maintenance costs (staff, energy, sludge management, reagents and maintenance) financial costs and taxes.

The internal benefit is expressed as:

$$B_I = \sum_{n=0}^n [(AVW_n * SPW_n) + (ACP_n * SPP_n) + (ACN_n * SPN_n) - (IC_n + OMC_n + FC_n + T_n)] \quad (2)$$

Where  $B_I$  = internal benefit (€),  $AVW$  = annual volume of reclaimed wastewater ( $m^3$ ),  $SPW$  = selling price of reclaimed wastewater (€/m<sup>3</sup>),  $ACP$  = annual volume of recovered phosphorus (kg),  $SPP$  = selling price of recovered phosphorus (€/kg),  $ACN$  = annual volume of recovered nitrogen (kg),  $SPN$  = selling price of recovered nitrogen (€/kg),  $IC$  = investment costs (€),  $OMC$  = operational and maintenance costs (€),  $FC$  = financial costs (€) and  $T$  = taxes (€) and  $n$  = year.

## 2.2 External benefit.

An externality is generated when an economic operation between two agents A and B, produces effects on a third agent C, without any monetary transaction between A and C, or between B and C. Externalities can also be produced by one agent and the impact may occur to the whole society (Madagán & Rivas, 1998).

Water recycling projects provide some externalities such as biological and chemical risks, health benefits, education services and especially environmental benefits. In this sense, the Environmental Protection Agency of the U.S. (EPA) argues that the use of reclaimed water provides the following environmental benefits (EPA, 1998): (i) can decrease diversion of freshwater from sensitive ecosystems, (ii) decreases discharge to sensitive water bodies, (iii) recycled water may be used to create or enhance wetlands and riparian habitats and (iv) can reduce and prevent pollution.

According to equation 1, the economic feasibility study of wastewater reuse projects requires, consider not only the internal impacts but also the quantification of the external impacts.

The external benefit is expressed as:

$$B_E = \sum_{n=0}^n (PE_n - NE_n) \quad (3)$$

Where  $B_E$  = external benefit (€),  $PE$  = positive externalities (€),  $NE$  = negative externalities (€) and  $n$  = year.

While any internal impact can be calculated directly in monetary units, the quantification of external impacts, due to the absence of market prices, requires the use

of economic valuation methods. This is the reason that in determining the economic feasibility of a wastewater reuse project, the estimation of the external impacts is the main obstacle due to the internal impacts are easily quantifiable based on prices determined by the market. All this implies that in most cases, decisions regarding wastewater reuse are based primarily on the financial costs of the projects without paying attention to non-monetizable impacts such as the environment protection.

However, a full economic feasibility study should be consider both internal and external impacts. A way to estimate the environmental benefits derived of wastewater regeneration and reuse projects, as mentioned in paragraph 1, is through the quantification of the shadow prices for the undesirable outputs obtained during wastewater regeneration.

According to Hernandez et al. (2010), wastewater recycling can be considered as a production process in which a desirable output (clean water) is obtained together with a series of pollutants (organic matter, phosphorus, nitrogen...). The contaminants extracted from wastewater are considered undesirable outputs because if they were dumped in an uncontrolled manner they would cause negative impacts on the environment.

The shadow prices valuation methodology for undesirable outputs (Färe et al. 2006) is based on the concept of directional distance function. Conceptually, a distance function generalizes the concept of conventional production functions and measures the difference between the outputs produced in the process under study and the outputs of the more efficient process. It is considered that the most efficient process is one that minimizes the inputs consumption and the undesirable outputs generation and maximizes desirable outputs generation. Denote inputs by  $x = (x_1, \dots, x_N) \in R_+^N$ , desirable outputs by  $y = (y_1, \dots, y_M) \in R_+^M$  and undesirable outputs by  $b = (b_1, \dots, b_J) \in R_+^J$ . Let  $g = (g_y, g_b)$  be a directional vector and assume  $g \neq 0$ . The directional output distance function is defined as:

$$D_0(x, y, b; g_y, g_b) = \text{Max} \{ \beta : (y + \beta g_y, b - \beta g_b) \in P(x) \} \quad (4)$$

The distance function gives the maximum expansion of desirable outputs and contraction of undesirable outputs that is feasible given the technology,  $P(x)$ .

Directional distance function parameterization is carry out with a quadratic form (Chambers, 1998). So unlike the translog function may be restricted to satisfy the translation property. Given the directional vector  $g = (1,1)$  and assuming  $k = 1, \dots, K$  states operating in  $t = 1, \dots, T$ , periods, the quadratic directional distance function for state  $k$  in period  $t$  is:

$$\begin{aligned}
D_o^t(x_k^t, y_k^t, b_k^t; 1,1) &= \alpha + \sum_{n=1}^N \alpha_n x_{nk}^t + \sum_{m=1}^M \beta_m y_{mk}^t + \sum_{j=1}^J \gamma_j b_{jk}^t + \frac{1}{2} \sum_{n=1}^N \sum_{n'=1}^N \alpha_{nn'} x_{nk}^t x_{n'k}^t \\
&+ \frac{1}{2} \sum_{m=1}^M \sum_{m'=1}^M \beta_{mm'} y_m y_{m'} + \frac{1}{2} \sum_{j=1}^J \sum_{j'=1}^J \gamma_{jj'} b_j b_{j'} + \sum_{n=1}^N \sum_{m=1}^M \delta_{nm} x_{nk}^t y_{mk}^t + \sum_{n=1}^N \sum_{j=1}^J \eta_{nj} x_{nk}^t b_{jk}^t \\
&+ \sum_{m=1}^M \sum_{j=1}^J \mu_{mj} y_{mk}^t b_{jk}^t
\end{aligned} \tag{5}$$

For parameters estimation  $(\alpha_0, \alpha_n, \alpha_{nn}, \beta_m, \beta_{mm'}, \gamma_j, \gamma_{jj}, \delta_{nm}, \eta_{nj}, \mu_{mj})$  the sum of the distance between production frontier and individual observations for each period should be minimized:

$$\begin{aligned}
Min &= \sum_{t=1}^T \sum_{k=1}^K [D_0^t(x_k^t, y_k^t, b_k^t; 1,1) - 0] \\
s.t. : \\
(i) & D_0^t(x_k^t, y_k^t, b_k^t; 1,1) \geq 0, k = 1, \dots, K, t = 1, \dots, T, \\
(ii) & \frac{\partial D_0^t(x_k^t, y_k^t, b_k^t; 1,1)}{\partial b_j} \geq 0, j = 1, \dots, J, k = 1, \dots, K, t = 1, \dots, T, \\
(iii) & \frac{\partial D_0^t(x_k^t, y_k^t, b_k^t; 1,1)}{\partial y_m} \leq 0, m = 1, \dots, M, k = 1, \dots, K, t = 1, \dots, T, \\
(iv) & \frac{\partial D_0^t(x_k^t, y_k^t, b_k^t; 1,1)}{\partial x_n} \geq 0, n = 1, \dots, N, \\
(v) & \sum_{m=1}^M \beta_m - \sum_{j=1}^J \gamma_j = -1; \sum_{m'=1}^M \beta_{mm'} - \sum_{j=1}^J \mu_{mj} = 0; m = 1, \dots, M; \\
& \sum_{j'=1}^J \gamma_{jj'} - \sum_{m=1}^M \mu_{mj} = 0; j = 1, \dots, J; \sum_{m=1}^M \delta_{nm} - \sum_{j=1}^J \eta_{nj} = 0; n = 1, \dots, N; \\
(vi) & \alpha_{nn'} = \alpha_{n'n}; \beta_{mm'} = \beta_{m'm}; m \neq n', \gamma_{jj'} = \gamma_{j'j}, j \neq j'
\end{aligned} \tag{6}$$

In order to obtain shadow prices for undesirable outputs it is necessary to examine the relationship between the maximal revenue function and the directional output distance function. Let  $p = (p_1, \dots, p_M) \in R_+^M$  represent desirable outputs prices and let  $q = (q_1, \dots, q_J) \in R_+^J$  represent undesirable output prices. The revenue function, which accounts for the negative revenue generated by the undesirable outputs, is defined as

$$R(x, p, q) = \text{Max}_{y,b} \{ py - qb : (y,b) \in P(x) \} \quad (7)$$

The revenue function,  $R(x, p, q)$ , gives the largest feasible revenue that can be obtained from inputs,  $x$ , when the process faces desirable outputs prices,  $p$ , and undesirable outputs prices,  $q$ .

The deduction of shadow prices for undesirable outputs means assuming that the shadow prices of an absolute desirable output coincides with the market prices. If  $y$  is a desirable output whose market price is  $p$  equal to its shadow price  $p_m$ , and if  $b$  is each of undesirable outputs and  $q_j$  is the shadow price of each undesirable, the absolute shadow prices are given by:

$$q_j = -p_m \frac{\partial D_0(x, y, b; g) / \partial b_j}{\partial D_0(x, y, b; g) / \partial y_m} \quad (8)$$

### 2.3 Opportunity cost.

The opportunity cost is defined as the value of goods in terms of a lost alternative use of those goods. Thus the opportunity cost will be given by that use to provider greater economic efficiency. In water reuse projects, the opportunity cost generally refers to land that the wastewater treatment plant occupies. Usually this land is not a great value but there may be situations where alternative uses generate significant incomes.

Replacing the equations (2) and (3) in the initially proposed general equation (1), the following expression is obtained:

$$\text{Max} B_T = \sum_{n=0}^n \left[ (AVW_n * SPW_n) + (ACP_n * SPP_n) + (ACN_n * SPN_n) \right] - (IC_n + OMC_n + FC_n + T_n) + (PE_n - NE_n) - OC_n \quad (9)$$

This paper shows a methodology to determine the economic feasibility of wastewater reuse projects taking into account both the internal and external impacts. Likewise, it is proposed the monetary valuation of the environmental benefits derived from a wastewater reuse project. To do this, using the concept of directional distance function, the shadow prices for undesirable outputs obtained in the process of wastewater recycling are quantified. This economic valuation, as shown equation (1) is necessary to determine the economic feasibility of these projects.

### 3. SAMPLE DATA DESCRIPTION

The study was undertaken in a sample of 13 wastewater treatment plants (WWTPs) whose effluent is reused for environmental uses. All plants are located in the coastal area of Valencia region (on the Mediterranean coast of Spain). All WWTPs carry out a similar process in which are obtained a desirable output (regenerated water) and four undesirable outputs: suspended solids (SS), nitrogen (N), phosphorus (P) and organic matter measure like chemical oxygen demand (COD). The inputs needed are energy, staff, reagents, waste management and others. These variables are described in table 1. The statistical information comes from *Entitat de Sanejament d'Aigües – EPSAR* and belongs to 2007.

Table 1: Sample description.

		<b>AVERAGE</b>	<b>DEVIATION</b>
<b>INPUTS</b> (€/m <sup>3</sup> )	Energy	0.072	0.021
	Staff	0.075	0.040
	Reagents	0.030	0.019
	Waste management	0.025	0.011
	Others	0.008	0.006
<b>DESIRABLE OUTPUT</b> (m <sup>3</sup> /year)	Regenerated water	3,166,290	2,400,849
<b>UNDESIRABLE OUTPUTS</b> (kg/m <sup>3</sup> )	SS	0.380	0.246
	N	0.028	0.017
	P	0.006	0.004
	COD	0.667	0.323

#### 4. RESULTS

Given that the aim of this paper is to quantify the environmental benefits of wastewater reuse projects, the methodology described in paragraph 2.2 has been applied in a sample of 13 WWTPs whose effluent is reused for environmental purposes.

The estimation of the directional distance function allows to obtain the shadow prices of each pollutant removed during the wastewater regeneration process for each WWTP under study. The shadow prices value, expressed in €/kg is shown in Table 2.

Table 2: Shadow prices for pollutants (€/kg).

WWTP	SS	N	P	COD
1	-0.010	-10.473	-62.840	-0.062
2	-0.001	-1.500	-9.000	-0.007
3	-0.008	-38.840	-45.826	-0.243
4	-0.002	-1.500	-2.166	-0.007
5	-0.059	-59.104	-70.792	-0.360
6	-0.004	-61.267	-367.602	-0.534
7	-0.001	-1.500	-3.519	-0.012
8	-0.007	-35.126	-42.126	-0.192
9	-0.003	-10.810	-28.579	-0.403
10	-0.010	-21.705	-130.227	-0.152
11	-0.016	-73.904	-167.671	-0.238
12	-0.006	-55.209	-63.809	-0.235
13	-0.007	-56.693	-78.794	-0.242
<b>AVERAGE</b>	<b>-0.010</b>	<b>-35.188</b>	<b>-82.535</b>	<b>-0.207</b>

The shadow prices obtained for undesirable outputs are negative due to from the viewpoint of the production process are not associated with marketable outputs that could generate an income. However, from an environmental point of view, these shadow prices can be interpreted positively because they represent the environmental benefits obtained of the wastewater reuse project.

Table 2 shows that for all plants studied the greatest environmental benefit is associated with phosphorus removal followed by nitrogen. This is because an excess of these two nutrients in the aquatic environment creates eutrophication problems. Nowadays, eutrophication is one of the major environment problems in the continental water bodies due to excessive growth of phytoplankton and algae produces a reduction in dissolved

oxygen levels and consequently there is a loss of aquatic biodiversity. We must keep in mind that nitrogen and phosphorus do not affect equally in eutrophication process. In inland waters, for algae growth the phosphorus is the limiting nutrient. In contrast, in maritime waters, the situation is more complex because is possible that the nitrogen is the limiting nutrient too. In the empirical application carried out, wastewater reuse is done for environmental purposes and consequently the regenerated effluent is gained to wetlands or other inland water bodies, for this reason the phosphorus shadow price value is greater than the obtained for nitrogen.

As regards the shadow price of organic matter (measure like COD), the obtained value is considerably lower than nitrogen and phosphorus. This is because water bodies have some capacity to self purify this pollutant. However, an excessive discharge of organic matter into the water bodies can cause oxygen deficiency getting to hypoxia and anoxia situations.

Once quantified the shadow prices of pollutants in €/kg and known the amount of pollutants removed per cubic meter of reclaimed water, the monetary value of the environmental benefit of wastewater reuse in €/m<sup>3</sup> and €/year is obtained directly.

Table 3: Environmental benefits of reuse project.

<b>WWTP</b>	<b>SS (€/m<sup>3</sup>)</b>	<b>N (€/m<sup>3</sup>)</b>	<b>P (€/m<sup>3</sup>)</b>	<b>COD (€/m<sup>3</sup>)</b>	<b>OVERALL (€/m<sup>3</sup>)</b>	<b>OVERALL (€/year)</b>
1	0.004	0.257	0.449	0.049	<b>0.759</b>	<b>6,430,921</b>
2	0.001	0.036	0.084	0.011	<b>0.132</b>	<b>946,054</b>
3	0.003	1.996	0.313	0.114	<b>2.425</b>	<b>12,638,415</b>
4	0.001	0.079	0.015	0.005	<b>0.099</b>	<b>272,081</b>
5	0.010	0.746	0.164	0.154	<b>1.073</b>	<b>3,156,721</b>
6	0.003	0.319	0.540	0.513	<b>1.376</b>	<b>3,719,680</b>
7	0.001	0.095	0.046	0.010	<b>0.151</b>	<b>207,631</b>
8	0.002	0.821	0.167	0.101	<b>1.091</b>	<b>1,804,343</b>
9	0.001	0.306	0.340	0.443	<b>1.090</b>	<b>1,033,818</b>
10	0.002	0.735	0.566	0.079	<b>1.383</b>	<b>4,137,498</b>
11	0.002	0.739	0.309	0.026	<b>1.075</b>	<b>3,299,762</b>
12	0.001	0.988	0.114	0.029	<b>1.131</b>	<b>1,148,305</b>
13	0.001	2.061	0.403	0.059	<b>2.525</b>	<b>2,203,367</b>
<b>AVERAGE</b>	<b>0.003</b>	<b>0.611</b>	<b>0.286</b>	<b>0.122</b>	<b>1.022</b>	<b>3,153,738</b>

The greatest environmental benefit, on average, is associated with nitrogen removal because it represents nearly 60% of the total benefit. With a percentage weight of 28% phosphorus follows in importance. These results are because such pollutants are those with a higher shadow price (see Table 2). The total environment benefit derived from a wastewater reuse project is very variable between different plants under consideration as the minimum value is 0.132 €/m<sup>3</sup> while the maximum is 2.525 €/m<sup>3</sup>. Weighted average, depending on the wastewater treated volume, is 1.022 €/m<sup>3</sup>.

Finally, information about the environmental benefit expressed in €/year is given. The integration of this value in equation (1) enables to obtain an indicator on the economic feasibility of a proposed wastewater reuse project, considering not only internal impacts but also externalities resulting from the project.

## **5. CONCLUSIONS**

As a result of significant technological progress on wastewater regeneration in recent years, at present, the feasibility of the wastewater reuse projects is primarily subject to economic and social aspects. Therefore, the economic analysis is becoming increasingly important in the development and implementation of wastewater regeneration and reuse projects. However, in most cases, the economic feasibility studies of these projects are exclusively focus on internal impacts without considering non-monetizable benefits derived from them such as the environment protection.

The valuation, in monetary terms, of the environmental externalities arising from a proposed wastewater reuse project is required to justify its economic feasibility. However, this is a complex task due to its nature of non-market. To do this, economists have developed different economic valuation methodologies.

This paper proposes the quantification of the shadow prices for the undesirable outputs obtained in wastewater regeneration process as an economic valuation method of environmental benefits associated with wastewater reuse.

There has been done an empirical application with a sample of 13 WWTPs whose effluent is reused for environmental purposes. The results show that the greatest environmental benefit is associated to prevent nitrogen and phosphorus discharges since

these nutrients are primarily responsible of inland water bodies eutrophication problems.

The monetary value of environmental benefits expressed in €/year, may be integrated into the economic feasibility study of a wastewater reuse project, thereby obtaining a useful viability indicator that takes into account not only internal impacts, but also the external too.

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