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Economic feasibility study for intensive and extensive wastewater treatment considering greenhouse gases emissions

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ABSTRACT

Economic feasibility assessments represent a key issue for selecting which wastewater treatment processes should be implemented. The few applications that exist focus on the positive economic value of externalities, overlooking the existence of negative externalities. However, wastewater treatment plants (WWTPs) consume a significant amount of energy, contributing to climate change. In this context, as a pioneering approach, greenhouse gas emissions (GHG) have been incorporated as a negative externality of wastewater treatment. Within this framework, this study aims to compare the economic feasibility of five technologies, both intensive and extensive, for small communities. The results show that both the investment and operation costs are higher for intensive than for extensive technologies. Moreover, significant differences in the value of negative externalities were observed. This study demonstrates that from an economic perspective, constructed wetland is the most suitable option for treating wastewater in small agglomerations.

1. Introduction

The achievement of the good ecological status of European water bodies specified by Directive 2000/60/EC (Water Framework Directive, WFD) is a challenge that must be addressed by European authorities before 2015. As reported for many River Basin Management Plans, one of the most common measures is to implement appropriate wastewater treatment systems in small agglomerations, i.e. urban agglomerations treating less than 1500 population equivalent (more information is available at http://circa.europa.eu/). The selection of the most suitable process involves many possible options, since a variety of objectives should be accomplished. Although a wide number of parameters must be considered, they may be categorized into three main groups: technical, economic and environmental.

The environmental impacts of wastewater treatment systems have been extensively investigated in the literature using the life cycle assessment (LCA) (e.g. Bargallo et al., 2006; Fuchs et al., 2011; Yildirim and Topkaya, 2012). In comparison, economic aspects have been traditionally considered through the financial assessment of facilities (e.g. Chen and Wagner, 2010; Wandl et al., 2006). However, a limited number of studies have examined both environmental and economic parameters together (e.g. Flores-Alsina et al., 2010; Rodríguez-Garcia et al., 2011).

Within the framework of environmental economics, since the 1980s, several methodologies have been developed aimed towards estimating the economic value of the environmental benefits of investment projects. The wastewater treatment sector has not escaped to this trend, with a significant number of studies being carried out to value the environmental benefits (positive externalities) associated towards preventing the discharge of pollutants (e.g. Godfrey et al., 2009; Hernández-Sancho et al., 2010).

The inclusion of environmental benefits in the assessment of the economic feasibility may be considered as a means of integrating economic and environmental variables in a single indicator, which primarily represents the net present value. Molinos-Senante et al. (2010) and Seguí et al. (2009) used a cost benefit analysis (CBA) to assess the economic feasibility of wastewater treatment projects, by considering both factors with market value and environmental benefits. Hence, the economic indicator of feasibility also provides information about environmental issues that were previously translated into monetary units. Despite theoretical developments

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(Hernández et al., 2006; Molinos-Senante et al., 2011a), it is considered that the assessment of the economic feasibility should include both positive and negative externalities; however, all empirical applications to date have primarily focused on positive externalities. In other words, it has been assumed that wastewater treatment is free of costs without market value (i.e. negative externalities).

Due to social and political concerns about climate change, there is growing interest in minimizing the consumption of energy in wastewater treatment plants (WWTPs). Energy consumption is twofold from the perspective of assessing the economic feasibility of the wastewater treatment process. On the one hand, it is an internal cost, since WWTPs operators must pay for the electricity consumed. On the other hand, and more interesting for our purpose, energy consumption is a negative externality, which should not be overlooked. WWTPs consume a significant amount of electricity (WERF, 2010), which involves the emission of greenhouse gases (GHG). The amount of energy needed for operating WWTPs depends on other factors of the implemented technology (Guimet et al., 2010). Hence, negative externalities of the wastewater treatment process vary depending on the technology being used. Although this issue has been overlooked in previous studies, it may play a vital role if the aim of the economic assessment is to compare technologies. In the context of small agglomerations, extensive technologies are generating interest as there are more environmentally friendly than intensive technologies (Yildirim and Topkaya, 2012). However, from an economic perspective, there remains little information about the differences between intensive and extensive technologies.

Against this background, the current study aimed to compare the economic feasibility of five technologies, both extensive and intensive, set-up for secondary treatment in small WWTPs. The integration of externalities in the evaluation also provides information related to the environmental performance of the technologies. Within this framework, we used the CBA tool as a decision criterion. Investment costs are predicted using cost functions, while operation and maintenance costs are based on real data from Spanish WWTPs. Positive externalities are represented by the environmental benefits derived from wastewater treatment, while GHG emissions are the negative externalities. Both types of externalities have been quantified in economic terms, and integrated in the economic assessment. The most innovative part of this research is the economic comparison of intensive and extensive technologies, and the integration of the economic value of GHG emissions into the assessment as a negative externality. The results of our research are expected to be of great use for decision makers as a decision support tool.

2. Material and methods

The cost benefit analysis (CBA) tool should be used to assess the economic feasibility of wastewater treatment technologies rather than traditional financial analysis. The main reason is that wastewater treatment involves significant environmental benefits that do not have market value. If economic feasibility is assessed through financial analysis, externalities derived from this process are excluded, whereas CBA includes internal and external impacts. Therefore, CBA reflects the true costs and benefits associated with wastewater treatment. Other reasons for selecting CBA as the preferred method are that: (i) it allows planners to take a long-term view of the project lifetime and (ii) it provides a project ranking, which, for all practical purposes, proves to be quite scientific and satisfactory.

Following Molinos-Senante et al. (2012), the net profit is the sum of internal and external benefits (Eq. (1)):

$$\mathrm{NP} = \sum B_{\mathrm{I}} + \sum B_{\mathrm{E}} \tag{1}$$

where NP is the net profit (total income − total costs), B_{I} is the internal benefit (internal income − internal costs) and B_{E} is the external benefit (positive externalities − negative externalities). A project is economically feasible if, and only if, NP > 0. The best option is the project that offers the highest net profit.

All of the items considered in Eq. (1) must be expressed in present values. By means of a properly chosen discount rate, the investor becomes indifferent about cash received at different points of time. The net present value is calculated as (Eq. (2)):

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{\mathrm{NP}_t}{(1+r)^t} \tag{2}$$

NPV is the net present value, NP_t is the net profit at time t; r is the discount rate and T is the project lifespan.

2.1. Internal benefit

The internal benefit is the difference between internal costs and internal incomes. It can be calculated directly, since both components have market value. In a wastewater treatment project, internal costs are composed of the investment costs (IC) and operation and maintenance costs (OMC) of the facility.

Cost functions are a useful tool to quantify IC, as they show the relationship between the dependent variable (cost) and independent variables (a set of representative variables of the process). Therefore, cost functions are widely used to predict the IC of wastewater treatment projects (Gratziou et al., 2006; Nogueira et al., 2007; among others).

Although OMC may also be quantified by cost functions, as reported by Hernández-Sancho et al. (2011) and Papadopoulos et al. (2007), in our specific case study, it has been considered more appropriate to use real data from a sample of Spanish WWTPs. Taking into account that all the wastewater treatment technologies evaluated in this paper are already implemented in Spain, we assume that the data provided directly from the operating companies is more reliable than information provided by cost functions. In any case, if the proposed methodology is used to assess the economic feasibility of technologies, in which real data is not available, the cost function approach should be appropriate.

The term 'internal income' could include the potential revenues from the sale of regenerated water. In fact, in areas subject to the harsh conditions of water stress, water reuse is a highly valuable non-conventional water source. However, in most cases, the regeneration of water involves tertiary treatments aimed to obtain high quality effluents. As the aim of this work is to compare the economic feasibility of a selection of technologies for secondary treatment, it is assumed that treated water discharged into the environment is not reused without generating any internal income.

Nowadays, to promote more sustainable wastewater treatment processes, technical studies about the recovery of nutrients and energy from wastewater are being developed (Marti et al., 2010). However, their full scale implementation remains very limited (Cornel and Schaum, 2009). Hence, the possible revenues from the sale of these by-products have been not included in the economic feasibility assessment.

2.2. External benefit

An externality is an effect of a purchase or use decision by one party (or group of parties) on another party who did not have a choice and whose interests were not taken into account (Hussen, 2004). According to this definition, the environmental benefits of wastewater treatment may be considered as positive externalities.

Based on the main goal of our paper, one important issue is that externalities do not have a market price. Hence, to integrate these externalities into the CBA it is necessary estimate their economic value through economic valuation methods. This requirement is a major limitation of applying CBA rather than of financial analysis.

From economic theory, several methodologies have been developed with the aim of estimating the value of environmental benefits derived from investment projects. While most methodologies are based on the demand approach (stated preference methods), methods based on the cost production approach have also been developed. Both approaches may be used to estimate the environmental benefits derived from wastewater in economic terms, as shown by Molinos-Senante et al. (2011a).

The use of shadow price valuation methodology for undesirable outputs (Färe et al., 1993), as carried out by Hernández-Sancho et al. (2010), constitute a pioneering approach for estimating the economic value of preventing the discharge of pollutants into the environment. The published literature (Hernández-Sancho et al., 2010; Molinos-Senante et al., 2011a, 2011b) demonstrates that the shadow price approach is a well-established method for estimating the economic value of environmental benefits from wastewater treatment. Moreover, shadow price quantification has very low costs compared to the expensive surveying processes required under the demand approach (Färe et al., 2001). Hence, in this paper, the quantification of environmental benefits from wastewater treatment is based on the shadow prices values obtained by Hernández-Sancho et al. (2010).

The current study focuses on indirect GHG emissions. Direct CO_2 emissions from wastewater are not considered in the assessment, as the IPCC Guidelines state that they are of biogenic origin and, therefore, should not be included in total national emissions (Doorn et al., 2006). In other words, following the methodology applied in LCA studies, GHG emissions are assessed based on the energy demand of WWTPs.

The GHG emissions associated with the consumption of electricity have been quantified with respect to the Spanish national electrical production mix. In a second step, these GHG emissions are converted to equivalent CO_2 emissions using 100-year global warning potential coefficients (IPCC, 2007). Specifically, the Spanish Energy White Book (Spanish Ministry of Industry, Tourism and Trace, 2009) reported that GHG emissions per kWh are 0.36 kg of CO_2 equivalent.

The next step is to quantify GHG emissions in monetary units to be integrated into the economic feasibility study as negative externalities. For this purpose, it should be noted that in the context of the Kyoto Protocol, a well-organized emissions trading has been developed. Since the European Union's Emissions Trading System (EU ETS) began operating in 2005, more than 11,000 power stations and industrial plants, accounting for 40% of total GHG emissions in the European Union, have been added. There is not a strict market price for CO_2 emissions; however, it depends on supply and demand, as well as other macroeconomic factors.

Based on the purpose of our research and, to minimize data variability, it is assumed that the market price of CO_2 emissions is the average price paid through the EU ETS during the 2009 to 2011 period. Hence, according to the SENDECO database (SENDECO, 2012), it is assumed that the market price of CO_2 is 13.4 € t^{-1}.

2.3. Sensitivity analysis to narrow the uncertainty

When assessing the economic feasibility of any investment project, uncertainty plays an important role. While several variables, such as the economic value of externalities or IC, are subject to a certain degree of uncertainty, the most important source of uncertainty is associated with the discount rate used to update the net profit. It is always difficult to select the discount rate because it involves the future value of money, the inflation rate and other risks. Moreover, the opportunity cost is also reflected in the discount rate because, when a particular project is invested in, it is assumed that this capital may not be invested elsewhere, in other words, there is an opportunity cost.

Several approaches may be used to narrow uncertainty, such as Bayesian network models, Monte Carlo simulations or tolerances models. However, the simplest approach is the "*ceteris paribus*" method, in which all model variables remain constant, except for the variable under evaluation.

Since the most important source of uncertainty is the discount rate in the current study, the "*ceteris paribus*" approach is followed to reduce uncertainty. Hence, two discount rates, 2.5% and 5.0%, are used to update the net profit.

3. Sample description

The sample used in this empirical application consists of 61 WWTPs located in the Spanish regions of Valencia and Catalonia (East of Spain). The capacity of all WWTPs is below than 2000 population equivalent (PE), since the study focuses on small agglomerations. Moreover, this selection minimizes the influence of scale economies, which are always present in wastewater treatment costs. All of the evaluated plants discharge their effluent into non-sensitive areas. Hence, intensive technologies do not include a specific process to remove nutrients. Data was supplied by the regional wastewater treatment authorities (Entitat de Sanejament d'Aigües –EPSAR and Agència Catalana de l'Aigua –ACA) for the year 2009. Table 1 shows the mean value of each variable, with the standard deviation being provided in parentheses.

The evaluated WWTPs were classified into five groups, according their secondary treatment process: (i) waste stabilization pond (PS); (ii) constructed wetland (W); extended aeration (EA); rotating biological contactors (RBC) and; (v) trickling filter (TF). The first two are extensive technologies, while the latter three are

Table 1
Description of the sample, average values and standard deviation in parentheses.

Technology	PS	*W*	EA	RBC	TF
Number of WWTPs	9	8	20	12	12
Population equivalent	825 (751)	1502 (1111)	1088 (589)	878 (714)	833 (687)
Volume (m^3/year)	60,245 (54,828)	109,636 (81,136)	105,094 (56,944)	54,667 (34,166)	64,792 (58,252)
Efficiency removal SS (%)	78.4 (27.8)	77.6 (15.2)	95.1 (2.0)	90.8 (5.6)	86.1 (19.0)
Efficiency removal COD (%)	77.7 (21.3)	82.3 (11.9)	93.8 (2.4)	85.8 (7.5)	81.1 (17.9)
Efficiency removal *N* (%)	37.8 (11.7)	49.3 (16.9)	67.9 (19.7)	50.5 (16.4)	36.5 (14.9)
Efficiency removal *P* (%)	43.0 (18.1)	43.3 (21.5)	64.8 (23.3)	45.0 (15.4)	40.7 (11.9)
Energy Consumption (kWh/m^3)	0.070 (0.018)	0.045 (0.021)	0.510 (0.149)	0.379 (0.158)	0.592 (0.849)

Source: EPSAR and ACA.

intensive technologies. Hence, it was possible to study whether there are economic and environmental differences between the two groups.

4. Results

First, this section summarizes the results relative to the performance of the five technologies being evaluated (Table 1). The removal efficiency of SS and COD is verified as being higher for the three intensive technologies than for the two extensive technologies. The performance of *N* within each group is not homogeneous, as the TF and EA extensive technologies exhibit the lowest and highest efficiency removal, respectively. EA technology exhibited the highest removal efficiency of *P*, while all other intensive and extensive processes performed similarly. In short, EA technology had the best performance for all evaluated pollutants.

Table 1 illustrates that intensive technologies consume about 10 times more energy than extensive technologies. Hence, this finding demonstrates the importance of including GHG emissions in the economic feasibility assessment of wastewater treatment technologies.

Before analysing the results of the economic feasibility study, it is important to clarify that, to select the most suitable option, a greater number of considerations should be accounted for, such as land requirements, influent and effluent characteristics, operation simplicity and so on. However, the main goal of the current study was obtain an economic indicator of feasibility to compare extensive and intensive technologies for wastewater treatment.

4.1. Economic feasibility study based on internal benefits

Following the methodology described in Section 2.1, in our case study, internal benefit involves IC and OMC. The use of the costs functions shown in Table 2 allowed IC to be quantified for each technology that was evaluated. The exponent of homogeneous function illustrates that EA and TF technologies were more affected by economies of scale, while W is the least impacted by this factor.

Table 2 verifies that on average higher values of both IC and OMC were obtained for intensive technologies compared to extensive technologies. This result shows that, from a strict economic point of view, extensive technologies are more suitable than intensive ones for small agglomerations. NVP is the indicator of the economic feasibility that should be calculated. However, in this case, the value was negative, as there were no internal incomes. Hence, the absolute NVP value is equal to the total annual equivalent cost (TAEC).

$$\mathrm{TAEC} = \frac{r(1+r)^t}{(1+r)^t - 1}\mathrm{IC} + \mathrm{OMC} \qquad (3)$$

where TAEC is the total annualized economic cost; IC is the investment cost; OMC is the operational and maintenance costs; *r* is the discount rate; and *t* is the useful life-span of the project.

Table 2
Cost functions for investment costs (y is the total cost expressed in €/PE and x is PE), mean IC (€/PE) and mean OMC (€/m^3).

Technology	Cost function for IC	IC (€/PE)	OMC (€/m^3)
PS	$y = 3897.7\,x^{-0.407}$	137.06	0.31
W	$y = 947.3\,x^{-0.188}$	248.39	0.32
EA	$y = 7946.0\,x^{-0.460}$	364.64	0.79
RBC	$y = 5635.3\,x^{-0.352}$	630.48	1.03
TF	$y = 12,237\,x^{-0.487}$	706.86	1.35

Source: Ortega de Ferrer et al. (2011); Tchobanoglous et al. (2003); Comas et al. (2004).

The selection of the life span of the technologies is always a controversial choice since it is well known that it depends on many factors including the maintenance of the facilities. In order to ease comparison between technologies, it has been considered that their lifetime should be the same. Previous studies have not shown a model life-span but they have used different values based on the main aim of the work.

When calculating TAEC, it was assumed that the expected life of a plant is 25 years and the discount rates are 2.5% and 5.0%. Moreover, to homogenate the size of all plants being evaluated, a specific case study was selected. Based on previous studies (Aragón et al., 2011; Salas et al., 2011), the implementation of a WWTP for a small community with an estimated population of 1500 PE and a flow rate of 400 m^3 per day was considered.

Fig. 1 shows the IC, OMC and TAEC with respect to the two discount rates for the five technologies evaluated in our case study. Fig. 1 illustrates the relevant differences among technologies, as the TAEC corresponding to TF (maximum) is 3.5 times higher than that associated with PS (minimum). Moreover, the current study verifies that the cost of extensive technologies is approximately half that of intensive ones. This result is important when considering small agglomerations because intensive technologies are more affected by scale economies than extensive one. Therefore, the results may have been different if the study had focused on large agglomerations. The high costs of RBC technology in relation to IC are of note. However, this technology did not have the highest TAEC, as it was partially compensated for by low OMC. This example illustrates the importance of using TAEC in the decision making process, because it incorporates both IC and OMC during the entire life-span of a WWTP.

While the results presented in this section may be useful for decision making processes, it should be noted that the performance of the five technologies evaluated here (Table 1) were different. Therefore, to integrate these environmental variables in the feasibility study, as described in Section 1, positive and negative externalities should be included in the assessment.

4.2. Economic feasibility study based on internal and external benefits

The second economic feasibility study carried out here includes both internal and external benefits. As reported in the methodology, the positive externalities are the environmental benefits derived from avoiding the discharge of pollutants into water bodies. This parameter has been quantified based on the shadow prices obtained by Hernández-Sancho et al. (2010) (Table 3). The negative externalities are GHG emissions, for which the economic

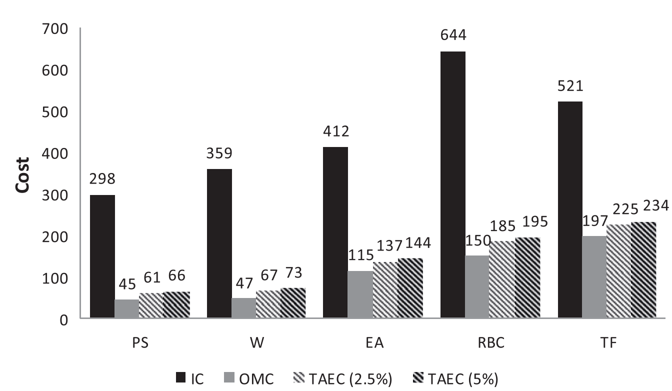

Fig. 1. Internal benefit for the selected technologies. IC (10^3 €); OMC (10^3 €/year); TAEC (10^3 €/year).

Table 3
Shadow prices for pollutants removed from wastewater (€/Kg).

Shadow prices in (€/Kg)			
SS	COD	*N*	*P*
−0.005	−0.098	−16.353	−30.944[a]

[a] This value means that for each Kg of P that is removed from wastewater, the environmental benefits obtained are 30.944 €. The same interpretation is applied for the rest of pollutants. Source: Hernández-Sancho et al. (2010).

value was determined based on the price paid through the EU ETS. The inclusion of internal and external impacts in the CBA allows an economic indicator of feasibility for the five evaluated technologies to be obtained.

The value of the shadow prices of positive externalities depends on the destination of the effluent (Hernández-Sancho et al., 2010). However, since our aim is to compare the economic feasibility of the five technologies, the selection of the destination is not relevant, as the rank will not change. Because the effluent is discharged into rivers in the majority of cases, this destination was selected.

The total environmental benefits resulting from wastewater treatment (Table 4) have been calculated based on the volume of pollutants removed during the treatment process (kg year^{-1}) and their shadow prices (€ Kg^{-1}). Hence, the economic value of the environmental benefits expressed in €/year was obtained. Taking into account the life-span of the WWTPs (25 years) and the two discount rates (2.5% and 5.0%), the environmental benefits were expressed as a present value (€).

Regarding the contribution of each pollutant to the total environmental benefit, for all technologies, the removal of *N* was observed to be the most beneficial action, as it represents around 65%–70% of the total benefit. In contrast, the removal of the pollutant SS involves the least generation of benefits, mainly due to its low shadow price. If we focus on the comparison of technologies, which is our main goal, EA presents the highest environmental benefit, while TF presents the lowest, closely followed by PS. Hence, it is not possible to establish general conclusions about differences between intensive and extensive technologies.

The next step in our evaluation is to determine the economic value of negative externalities. GHG emissions (t/year), and hence economic value (€/year), were estimated based on the consumption of electricity, using the "market value" of the EU ETS. As well as positive externalities, the economic value of negative externalities was also updated to present values (Table 5).

Table 5 demonstrates significant differences in the value of negative externalities between intensive and extensive technologies. Because W technology has the lowest energy consumption, it also has the lowest negative externality. Of note is the high negative externality associated to EA technology, due to the large amount of energy used in this process.

Once both internal and external benefits have been quantified and updated, we may calculate the present net value associated with each technology being evaluated. Table 6, Fig. 2 and Fig. 3 show that the two extensive technologies are feasible, since their present net value is positive. In contrast, the only feasible intensive technology is EA, with RBC and TF not being feasible. Therefore, from an economic point of view, the most suitable option for small agglomerations is *W*, since it presents the highest present net value.

Table 4
Environmental benefits for the five technologies evaluated (positive externalities).

	Environmental benefits (€/year)					Environmental benefits for all life-span (€)	
	SS	COD	*N*	*P*	Total	*r* = 2.5%	*r* = 5.0%
PS	163	8338	56,406	22,341	87,247	1,607,478	1,229,659
W	161	8832	73,566	22,497	105,056	1,935,584	1,480,648
EA	198	10,066	101,321	33,667	145,252	2,676,168	2,047,167
RBC	189	9207	75,357	23,380	108,133	1,992,274	1,524,014
TF	179	8703	54,466	21,146	84,493	1,556,737	1,190,845

Table 5
GHG emissions and their economic value for the five technologies evaluated (negative externalities).

	Energy consumption (kWh/m^3)	CO_2 equivalent (t/year)	Negative externalities (€/year)	Negative externalities for all life-span (€)	
				r = 2.5%	*r* = 5.0%
PS	0.0700	3.68	49.28	908	695
W	0.0450	2.36	31.66	583	446
EA	0.5100	26.81	359.21	6618	5063
RBC	0.3642	19.14	256.47	4725	3615
TF	0.3718	19.54	261.89	4825	3691

Table 6
External benefit, internal benefit and net present value in € for a discount rate of 2.5% and 5.0%.

	r = 2.5%			*r* = 5.0%		
	External benefit (€)	Internal benefit (€)	Net present value (€)	External benefit (€)	Internal benefit (€)	Net present value (€)
PS	1,606,570	−1,122,034	484,536	1,228,964	−928,357	300,608
W	1,935,000	−1,225,817	709,184	1,480,201	−1,022,155	458,046
EA	2,669,550	−2,526,631	142,919	2,042,104	−2,029,688	12,416
RBC	1,987,549	−3,401,070	−1,413,521	1,520,399	−2,753,021	−1,232,622
TF	1,551,912	−4,149,961	−2,598,049	1,187,154	−3,297,065	−2,109,912

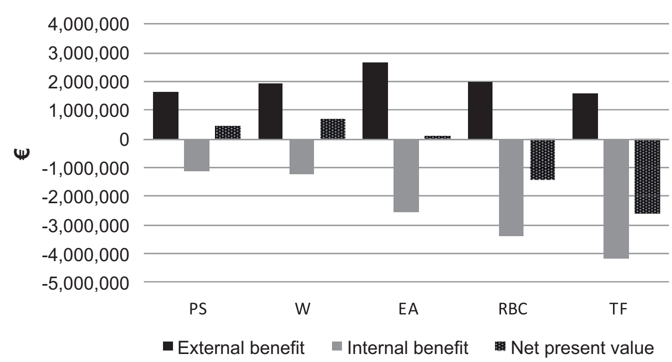

Fig. 2. External benefit, internal benefit and net present value in € for a discount rate of 2.5%.

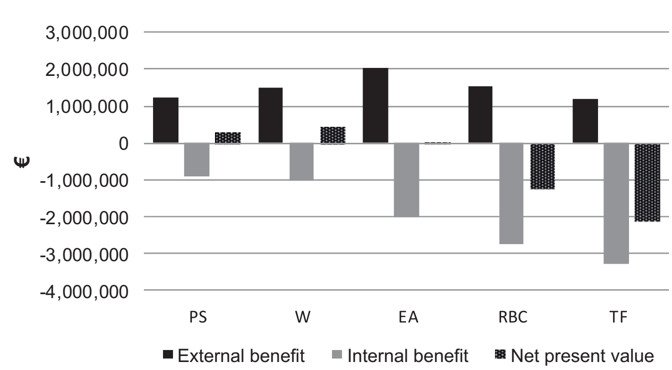

Fig. 3. External benefit, internal benefit and net present value in € for a discount rate of 5.0%.

When focussing on the contribution of internal and external benefits to the present net value, relevant differences are also observed among technologies. In general terms, intensive technologies (EA and RBC) present higher external benefits than extensive technologies. In other words, the environmental benefits derived from wastewater treatment minus the negative impacts associated with energy consumption are higher for intensive technologies than for extensive ones. This result is due to the efficiency of pollutant removal being greater for intensive technologies compared to extensive ones, with GHG emissions also being larger. The case of EA is noteworthy, since while it has the greatest external benefit, its high cost involves a present net value very close to zero. From an economic perspective, TF is the least suitable option, since it has the lowest present net value, due to it presenting the lowest external benefits and the highest cost (internal benefit).

5. Conclusions

Economic feasibility studies provide essential information for decision making processes. This analysis requires the inclusion of both internal and external benefits. However, nowadays, very few studies include the economic value of externalities associated with wastewater treatment, and those that do only focus on positive externalities (environmental benefits). To overcome this limitation and as a pioneering approach, we considered greenhouse gas (GHG) emissions as a negative externality of wastewater treatment. Its economic valuation was based on the market price of CO_2 emissions paid through the European Union Emissions Trade System.

The current study presents a comparison of the economic feasibility of five technologies, both extensive and intensive, that perform secondary treatment for small communities. As a result, a cost benefit analysis was developed that incorporated the internal and external benefits of each technology being evaluated.

Regarding internal benefit, the current study showed that both investment costs and operation and maintenance costs are higher for intensive technologies compared to extensive technologies. Hence, from an economic perspective, extensive technologies are more suitable for small agglomerations. The assessment of the total annual equivalent cost verifies that TF is the most expensive technology, while PS is the cheapest.

The economic valuation of the positive externalities illustrated that EA technology generates the greatest environmental benefit, due to its high pollutant removal efficiency. However, it is not possible to establish general conclusions about differences between intensive and extensive technologies. In contrast, significant differences in the value of negative externalities were observed between intensive and extensive technologies. W technology had the lowest GHG emissions, while EA had the highest.

The present net value, which was calculated from both internal and external benefits, shows that the two extensive technologies are feasible, while only one intensive technology (EA) presents a positive value. This study illustrates that, from an economic perspective, the most suitable option for small agglomerations is constructed wetland technology as it produced the highest present net value.

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References

Aragón, C.A., Salas, J.J., Ortega, E., Ferrer, Y., 2011. Lacks and needs of R&D on wastewater treatment in small populations. Water Practice and Technology 6 (2).

Bargallo, S., Cirelli, G.L., Consoli, S., Matarazzo, A., Pappalardo, N., Toscano, A., 2006. LCCA of a Natural Treatment System for Agricultural Wastewater Reuse: Experience in Eastern Sicily, Proceedings of the IWA 7th Specialised Conference on Small Water and Wastewater Systems, 7–10 March 2006, Mexico City, Mexico.

Chen, H., Wagner, M., 2010. Investment and operating cost of municipal wastewater treatment plants in China. Environmental Journal of Environment and Waste Management 5 (3–4), 316–325.

Comas, J., Alemany, J., Poch, M., Torrens, A., Salgot, M., Bou, J., 2004. Development of a knowledge-based decision support system for identifying adequate wastewater treatment for small communities. Water Science and Technology 48, 393–400.

Cornel, P., Schaum, C., 2009. Phosphorus recovery from wastewater: needs, technologies and costs. Water Science & Technology 59, 1069–1076.

Doorn, M.R.J., Towprayoon, S., Manso-Vieria, S.M., Irving, W., Palmer, C., Pipatti, R., et al., 2006. Wastewater treatment and discharge. In: Eggleston, S., Buendia, L., Miwa, K., Tanabe, K. (Eds.), Waste. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IGES, Japan, pp. 6.1–6.28.

Färe, R., Grosskopf, S., Lovell, C.A., Yaisawarng, S., 1993. Derivation of shadow prices for undesirable outputs: a distance function approach. Review of Economics and Statistics 75 (2), 374–380.

Färe, R., Grosskopf, S., Weber, W.L., 2001. Shadow prices of Missouri public conservation land. Public Finance Review 29 (6), 444–460.

Flores-Alsina, X., Gallego, A., Feijoo, G., Rodriguez-Roda, I., 2010. Multiple-objective evaluation of wastewater treatment plant control alternatives. Journal of Environmental Management 91, 1193–1201.

Fuchs, V.J., Mihelcic, J.R., Gierke, J.S., 2011. Life cycle assessment of vertical and horizontal flow constructed wetlands for wastewater treatment considering nitrogen and carbon greenhouse gas emissions. Water Research 45, 2073–2081.

Godfrey, S., Labhasetwar, P., Wate, S., 2009. Greywater reuse in residential schools in Madhya Pradesh, India. A case study of cost-benefit analysis. Resources, Conservation and Recycling 53, 287–293.

Gratziou, M., Tsalkatidou, M., Kotsovinos, N.E., 2006. Economic evaluation of small capacity sewage processing units. Global Nest Journal 8 (1), 52–60.

Guimet, V., Kelly, R., Doung, F., Rosina, M., Audic, J.M., Terry, J.M., 2010. Green Energy Resource: Research and Learning Experiences from Wastewater Treatment Plants. Proceedings of IWA World Water Congress, Montreal (Canada).

Hernández-Sancho, F., Molinos-Senante, M., Sala-Garrido, R., 2010. Economic valuation of environmental benefits from wastewater treatment processes: an empirical approach for Spain. Science of the Total Environment 408, 953–957.

Hernández-Sancho, F., Molinos-Senante, M., Sala-Garrido, R., 2011. Cost modelling for wastewater treatment processes. Desalination 268, 1–5.

Hernández, F., Urkiaga, A., De las fuentes, L., Bis, B., Chiru, E., Balazs, B., Wintgens, T., 2006. Feasibility studies for water reuse projects: an economical approach. Desalination 187, 253–261.

Hussen, A.M., 2004. Principles of Environmental Economics. Routledge, New York.

IPCC (Intergovernmental Panel on Climate Change), 2007. Summary for policy makers. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York.

Marti, N., Pastor, L., Bouzas, A., Ferrer, J., Seco, A., 2010. Phosphorus recovery by struvite crystallization in WWTPs: influence of the sludge treatment line operation. Water Research 41, 2371–2379.

Molinos-Senante, M., Hernández-Sancho, F., Sala-Garrido, R., 2010. Economic feasibility study for wastewater treatment: a cost-benefit analysis. Science of the Total Environment 408, 4396–4402.

Molinos-Senante, M., Hernández-Sancho, F., Sala-Garrido, R., 2011a. Cost-benefit analysis of water reuse projects for environmental purposes: a case study for Spanish wastewater treatment plants. Journal of Environmental Management 92, 3091–3097.

Molinos-Senante, M., Hernández-Sancho, F., Sala-Garrido, R., 2012. Economic feasibility study for new technological alternatives in wastewater treatment process: a review. Water Science & Technology 65, 898–906.

Molinos-Senante, M., Hernández-Sancho, F., Sala-Garrido, R., Garrido-Baserba, M., 2011b. Economic feasibility study for phosphorus recovery processes. AMBIO 40, 408–416.

Nogueira, R., Ferreira, I., Janknecht, P., Rodriguez, J.J., Oliveira, P., Brito, A.G., 2007. Energy-saving wastewater treatment systems: formulation of cost functions. Water Science and Technology 56, 85–92.

Ortega de Ferrer, E., Ferrer, Y., Salas, J.J., Aragón, C., Real, A., 2011. Manual para la implementación de sistemas de depuración en pequeñas poblaciones, first ed. CENTA, Madrid (in Spanish).

Papadopoulos, B., Tsagarakis, K.P., Yannopoulos, A., 2007. Cost and land functions for wastewater treatment projects: typical simple linear regression versus fuzzy linear regression. Journal of Environmental Engineering, ASCE 133, 581–586.

Rodríguez-Garcia, G., Molinos-Senante, M., Hospido, A., Hernández-Sancho, F., Moreira, M.T., Feijoo, G., 2011. Environmental and economic profile of six typologies of wastewater treatment plants. Water Research 45, 5997–6010.

Salas, J.J., Ortega, E., Ferrer, Y., Aragón, C., 2011. Current Situation of Sanitation and Wastewater Treatment in Small Spanish Agglomerations. III International Congress SmallWat11, Girona (Spain).
Seguí, L., Alfranca, O., García, J., 2009. Techno-economical evaluation of water reuse for wetland restoration: a case study in a natural park in Catalonia, Northeastern Spain. Desalination 246, 179–189.
SENDECO (Carbon dioxide emission allowances electronic trading system), 2012. (accessed 15.04.12.). Available from: http://www.sendeco2.com/index-uk.asp.
Spanish Ministry of Industry, 2009. Tourism and Trace, Spain Energy White Book (in Spanish). (accessed 15.04.12.). Available from: http://www.mityc.es/energia/balances/Balances/LibrosEnergia/Energia2009.pdf.
Tchobanoglous, G., Burton, F.L., Stensel, H.D., 2003. Wastewater Engineering: Treatment and Reuse, fourth ed. Metcalf & Eddy, McGraw-Hill, Boston.
Wandl, G., Kroiss, H., Svardal, K., 2006. The main wastewater treatment plant of Vienna: an example of cost-effective wastewater treatment for large cities. Water Science and Technology 54 (10), 79–86.
WERF (Water Environment Research Foundation), 2010. Overview of State Energy Reduction Programs and Guidelines for the Wastewater Sector. OW06R07a/OW06R07b.
Yildirim, M., Topkaya, B., 2012. Assesing environmental impacts of wastewater treatment alternatives for small-scale communities. Clean – Soil, Air, Water 40 (2), 171–178.