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Economic and environmental performance of wastewater treatment plants: Potential reductions in greenhouse gases emissions

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ABSTRACT

Sanitation and wastewater treatment are essential for protecting human health and environmental sustainability. Treatment processes are not free of environmental impacts; consequently assessment of the environmental performance of wastewater treatment plants (WWTPs) has gained interest in recent years. Unlike other methods, a direct approach is followed to estimate environmental performance indicators (EPIs) using data envelopment analysis (DEA), i.e. an index of overall performance is directly obtained. The present study represents pioneering work to integrate environmental impacts in the assessment of the efficiency of WWTP estimating pure (PEPI) and mixed (MEPI) environmental performance indices for a sample of 60 Spanish WWTPs. Both direct and indirect greenhouse gas (GHG) emissions were considered as undesirable outputs. The best functioning WWTPs to be used as references were identified, and the potential for GHG reductions was quantified. A second-stage analysis was conducted to isolate factors affecting WWTP environmental performance. The results of this study are valuable for WWTP operators and policy makers, since the benchmark procedure allows support for environmental and managerial decision-making.

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1. Introduction

Sanitation and wastewater treatment are essential for protecting human health, and maintain or achieve good ecological status of water bodies (IOC/UNESCO, 2011). Consequently, access to basic sanitation is part of the 2015 water and sanitation target under the Millennium Development Goal, and many developed countries have adopted regulations regarding this issue, including the EU Directive 91/271/EEC and the US Clean Water Act. Despite the benefits of wastewater treatment are obvious, it also results in environmental impacts (Friedrich et al., 2009), such as eutrophication and contributions to climate change (Lassaux et al., 2007; Kalmar et al., 2013).

In the light of these environmental threats, the wastewater treatment industry has been subject to government policy aimed at improving its environmental performance. At the same time, industry faces economic constraints to prevent increased operation and maintenance costs of wastewater treatment plants (WWTPs). Therefore, in recent years the concept of "eco-efficiency[1]" has been universally recognized as a component of sustainability, since it is defined as a ratio of economic value added to environmental damage (Kuosmanen and Kortelainen, 2013). A number of alternative measures or indicators have been suggested to assess the eco-efficiency of firms, services, facilities, and countries (hereinafter units) (Tyteca, 1996). The measures of the eco-efficiency range from simple indicators to more sophisticated ones. Life cycle assessment (LCA), multi-criteria analysis (MCA) and environmental performance indicators (EPIs) are three instruments to assess the environmental attributes of these units (Lozano-Oyola et al., 2012). On the one hand, the first two measures can be considered indirect, since sub-indicators (climate change potential, eutrophication potential, and energy consumption, among others) are first identified, then normalized and integrated into an overall index. On the other hand, EPI estimates follow a direct approach, since an index is directly obtained from the observed input quantity of the desirable and undesirable unit outputs evaluated (Zhou et al., 2012). In the framework of the wastewater treatment industry, EPIs can provide meaningful guidelines from managerial and environmental perspectives, since information costs, technical performance (pollutants removed) and environmental impacts are aggregated into a simple index.

Data Envelopment Analysis (DEA)[2] is a non-parametric method originally developed to evaluate the efficiency and productivity of Decision Making Units (DMUs) which are units in DEA terminology. Several studies reported DEA is an excellent approach to examine the environmental performance of DMUs (Korhonen and Luptacik, 2004; Barba-Gutierrez et al., 2009; Sanjuan et al., 2011). The primary advantages to DEA methodology relative to other approaches in environmental performance evaluation are as follows: (i) different environmental impact dimensions can be summarized in a single index that captures the dependence between inputs and outputs (Lozano et al., 2009); (ii) DEA does not require any subjective weighting procedure of environmental impacts, since the optimal weights are assigned through rigorous mathematical programming (Egilmez et al., 2013) and; (iii) the methodology evaluates DMU performance involving multiple outputs and inputs expressed in different units of measure.

While traditional DEA models utilize two factor categories (inputs and outputs), the extension of DEA approach into EPIs suggest a third factor, namely undesirable outputs (Tyteca, 1997), which are the environmental impacts involved in the process.

To date, several DEA studies have been developed to evaluate the techno-economical efficiency of WWTPs under different scenarios, and with a variety of objectives. For example, Tupper and Resende (2004) combined DEA with econometric estimates to examine water and sewage sector efficiency in Brazil; Hernández-Sancho et al. (2011a) assessed energy efficiency using a non-radial DEA model; Sala-Garrido et al. (2011) compared the efficiency of wastewater treatment technologies using a DEA metafrontier model; and Da Cruz et al. (2012) compared the efficiency of water utilities in Italy and Portugal. However, despite the wide application of DEA models in the wastewater treatment industry, previous studies have not integrated undesirable outputs or environmental impacts in WWTP performance assessments.

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[1] More details about eco-efficiency concepts can be found in Kortelainen (2008).

[2] More details about DEA methodology can be found in Charnes et al. (1996) and Cooper et al. (2006).