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Research article

Efficiency of wastewater treatment facilities: The influence of scale economies

Vicent Hernández-Chover*, Águeda Bellver-Domingo, Francesc Hernández-Sancho

Water Economics Group, Department of Applied Economics II, University of Valencia, Avda. Tarongers S/N, 46022, Valencia, Spain

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ABSTRACT

The water cycle, from catchment to discharge, is a sector that involves an important investment and operation and maintenance costs. In particular, sewage treatment is a challenge for governments because they are having to consider economic, environmental, and social aspects. Within the European Union, implementation of Directive 91/271/EEC is responsible for the location of wastewater treatment facilities in the territory, due to the requirement that all urban areas must have this infrastructure to reduce the environmental impact of treated water in water bodies. Different sizes of municipalities affect the design of each wastewater treatment plant (WWTP) and cause variations in the operation process. The presence of scale economies in this sector has a significant influence on the efficiency of the wastewater treatment process and has a direct impact on the operational costs. Based on the pursuit of economic and environmental efficiency, this analysis extends the scope of the current literature because it recommends a specific, population equivalent (p.e.) range for which it would be suitable to achieve efficiency in wastewater treatment facilities—shedding light on the open debate about scale economies in WWTPs.

1. Introduction

The growth of world population is associated with an increase in water demand. The consequences of this increase are twofold: on the one hand it endangers the ecosystem water balance, and on the other hand the volume of resultant wastewater is high. This situation forces authorities to monitor and improve wastewater treatment processes to minimize the environmental impact and ensure the good ecological status of water bodies. Wastewater treatment processes are regulated by law, which establishes the criteria and environmental standards that must be achieved. Achieving these criteria involves carrying out efficient management of WWTPs. The efficiency of WWTPs not only presumes the removal of all pollutants included in the regulations, but it also means that adopting an approach that minimizes inputs is necessary to prevent overruns in the wastewater treatment process (Molinos-Senante et al., 2013).

Under this approach WWTPs become a productive unit, where the main input is wastewater and the desired output is treated water, suitable for other uses (Sala-Garrido et al., 2011). The European Union environmental standards are being implemented to protect all stages of the water cycle, due to the sensitivity of the resource and the pressure to which it is subjected by urban agglomerations. Among the most important of these regulations are Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment and Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (EUR-Lex, 2016). Directive 91/271/EEC aims to standardize the management of urban wastewater to ensure adequate environmental protection through improving the quality of WWTP effluent. The Directive requires that all urban agglomerations must have collectors and WWTPs. In the case of those urban agglomerations in sensitive areas (wetlands or lakes), effluent quality standards must become more restrictive (protecting the ecosystem against eutrophication). The most visible result of the implementation of Directive 91/271/EEC is an increase in the number of small WWTPs operating in the EU[1] (Fraquelli and Giandrone, 2003); all agglomerations of less than 2000 population equivalent[2] (p.e.) must have a WWTP, and urban agglomerations between 2000 and 10,000 p.e. must install collectors and WWTPs with

* Corresponding author.
E-mail address: vicent.hernandez@uv.es (V. Hernández-Chover).

[1] For example, in Spain there are 3450 municipalities with fewer than 2000 p.e. that directly affect protected natural areas (Ministry of Agriculture, Food and Environment, 2015).

[2] One population equivalent (p.e.) is defined as "the organic biodegradable load having a five-day biochemical oxygen demand (BOD5) of 60 g of oxygen per day" by the Council Directive 91/271/ECC of 21 May concerning urban wastewater treatment.

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secondary treatment. Before the Directive, WWTPs were built only in large urban centres (Molinos-Senante et al., 2012).

Directive 2000/60/EC, better known as the Water Framework Directive (WFD), profoundly changed the existing water policy because its goals of preventing water deterioration, improving the ecological status of water bodies, and adhering to the sustainable use of water are responsible for the legal and structural reform that European States Members must have in their water policies. The WFD takes a multidisciplinary approach: it includes the economy as an assessment mechanism to reach its goals. The environmental and economic dimensions are integrated to form an important part of the designing process for the implementation and regulation of water policy.

The search for means to properly maintain the ecological status of water bodies (surface water and underground) has caused a substantial increase in the number of WWTPs managed by European States Members. To this increase in WWTPs is joined the environmental and economic standards compliance included in the WFD and, hence, an uncertainty scenario has been created due to the high volume of new responsibilities. The challenges for the authorities on wastewater treatment are twofold: to ensure the suitable quality of treated water while the operational costs are being reduced (Molinos-Senante et al., 2013). It is necessary to assess the efficiency of WWTPs to identify potential improvements in economic and environmental issues (Berg, 2013). Public management of the water cycle implies that managers and governments must search for efficiency at all stages to ensure service quality, savings in operating costs, and suitable environmental management of the water resource (lo Storto, 2015; Marques, 2008).

The use of a benchmarking approach is the best way for both the managers of the WWTPs and the authorities to achieve the efficient performance of the different facilities. This methodology allows us to know how the system works and what inputs and outputs are affecting the efficiency or inefficiency. In addition, we can identify the influence of scale economies on the WWTPs located in different places. The results could help in planning future actions, such as considering the optimal size of the facilities to ensure suitable wastewater treatment.

The methodology used for efficiency analysis is a nonparametric method called Data Envelopment Analysis (DEA) and developed by Charnes et al. (1978). The main advantage of this approach is the high degree of flexibility, which makes it unnecessary to define a specific functional form (Medal-Bartual et al., 2012). The DEA is a decision support tool that can be implemented in a wide range of sectors, such as energy, industry, universities, airlines, and banking (Rácz and Vestergaard, 2016; Lee and Worthington, 2016; Stewart et al., 2016; lo Storto, 2015; Christopoulos et al., 2015; Sueyoshi and Wang, 2014). It is a reliable tool to evaluate the efficiency of different production units, allowing the introduction into the analysis of multiple inputs and outputs of the production process (Chakraborty, 2015; Aristovnik, 2015; Qasemi-Kordkheili et al., 2014; Blum, 2014; Zhong et al., 2011; Hollingsworth, 2008; Chauhan et al., 2006; Viton, 1986).

The tightening of environmental legislation has promoted the use of DEA to calculate the environmental efficiency of production processes (Zha et al., 2016; Halkos and Papageorgiou, 2016; Cruz et al., 2013; Rogge and De Jaeger, 2012; Carvalho and Marques, 2011; De Witte and Marques, 2009; Zhou et al., 2006; Hernández-Sancho et al., 2000). The drinking water supply and water sanitation services are also amenable to the DEA methodology because they are considered as productive processes; they use inputs to obtain the desirable output expressed as drinking water or treated water (Hernández-Sancho et al., 2010). Thus the methodology sheds light on the operation and it informs the need to implement technological improvements to meet environmental quality objectives and cost-recovery parameters established by the WFD (Marques, 2008; García-Valiñas and Muñiz, 2007). There is a wide variety of studies that have used DEA methodology to determine the efficiency of water use and management (Morales and Heaney, 2015; Carvalho et al., 2015; Njiraini and Guthiga, 2013; Kulshrestha and Vishwakarma, 2013; lo Storto, 2013; Gupta et al., 2012; Byrnes et al., 2010; Abbott and Cohen, 2009; Speelman et al., 2008; Marques, 2008; Díaz et al., 2004; Thanassoulis, 2000). The specific case of wastewater treatment efficiency has been evaluated considering the maximization of pollutants removed (better effluent quality) according to the technology used (Benedetti et al., 2010; Oa et al., 2009; Mufioz et al., 2008; Baeza et al., 2004). This is because there are studies that justify the importance of pollutant removal in the treatment process as a relevant factor for knowing the efficiency of WWTPs (Molinos-Senante et al., 2014).

The water sector—from drinking water to wastewater treatment—is influenced by the existence of scale economies. The analysis of García and Thomas (2001) shows the existence of scale economies in the French drinking water network. Their study concludes that supply network size influences scale economies. This study is not alone, as there is a wide variety of authors who have analysed the relationship between water management and scale economies (Worthington and Higgs, 2014; Carvalho and Marques, 2014; Guo et al., 2014; Molinos-Senante et al., 2013; Saal et al., 2013; Abbott and Cohen, 2009; Nauges and Berg, 2008; Nauges and van den Berg, 2007; Torres and Morrison Paul, 2006; Fabbri and Fraquelli, 2000). These studies highlight the existence of scale economies in the water sector, and their findings aim to improve municipal management and decision-making processes. Given this evidence it is reasonable to think that wastewater treatment will exhibit the same pattern; i.e., there will be a reduction in the unitary cost of wastewater treatment as the size of WWTP increases (Fraquelli and Giandrone, 2003). Thus, the increased number of WWTPs caused by Directive 91/271/EEC may be responsible for variations in wastewater treatment efficiency (Molinos-Senante et al., 2012). We must ask ourselves if WWTPs' size (in terms of the number of p.e. they are designed for) influences their ability to remove pollutants as well as the economic costs associated with treatment (Cesaroni and Giovannola, 2015; Hernández-Sancho et al., 2011a).

Analysis of this issue is important because the dilemma is important. Is it better to construct many small WWTPs or a larger WWTP for multiple urban agglomerations? That is, to what extent does size affect WWTP effluent quality and the efficiency of the treatment process (Guerrini et al., 2015; Worthington and Higgs, 2014)? There is an open debate about this, which affects the construction of new WWTPs, because there is no consensus about optimal size. Studies in the literature analyse the scale economies, but results are inconclusive because the water sector is affected by diseconomies of scale (Berg and Marques, 2011; Carvalho et al., 2012). Taking into account both approaches, the search for an optimal facility size is a challenge for any investigation (Kim and Clark, 1988, Bhattacharyya et al., 1995, Fabbri and Fraquelli, 2000). This dilemma affects economic efficiency (when efficiency is lower, operational costs will increase) and environmental efficiency (because the sewage treatment plant has to be designed in accordance with the number of p.e. to be connected to the sanitation network; thus imbalances in pollution loads affect the effluent quality). This leads us to think that the influence of scale economies in WWTPs is high. A detailed analysis leading to identification of the causes responsible for previous imbalances is necessary, because there is no consensus in the literature about the optimal size for WWTPs (Carvalho and Marques, 2014).

Based on the assumptions above, this study aims to evaluate efficiency and scale economies in a sample of WWTPs located in the Valencian Region, under an economic and environmental point of view. This approach serves as a starting point to learn the influence of scale economies in wastewater treatment processes. The influence of scale economies in the performance of WWTPs enables to identify the optimal size of WWTPs. The sample under analysis represents the dilemma between small and big WWTPs, because in the Valencian Region there are many small municipalities that have an obligation to provide wastewater treatment. The contribution of this study is to suggest the optimal size for future WWTPs to achieve maximum efficiency. Through the methodology proposed in our work, it has been possible to