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Modelling the energy costs of the wastewater treatment process: The influence of the aging factor

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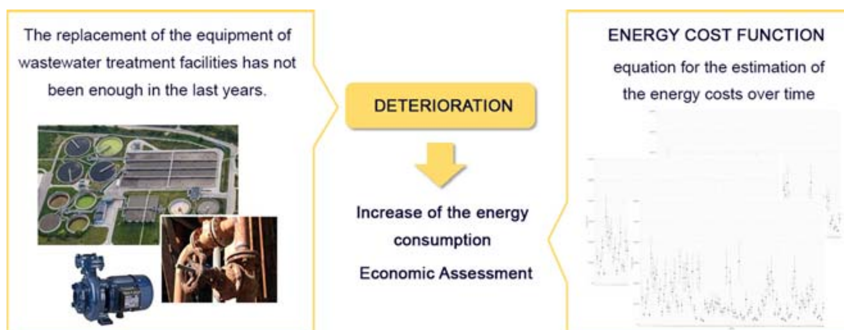
HIGHLIGHTS

- The energy cost of small and medium WWTPs are sensitive to the effects of the deterioration.
- A dynamic energy cost model has been developed.
- The energy cost model could become a useful decision making tool.

GRAPHICAL ABSTRACT



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ABSTRACT

Wastewater treatment plants (WWTPs) are aging and its effects on the process are more evident as time goes by. Due to the deterioration of the facilities, the efficiency of the treatment process decreases gradually. Within this framework, this paper proves the increase in the energy consumption of the WWTPs with time, and finds differences among facilities size. Accordingly, the paper aims to develop a dynamic energy cost function capable of predicting the energy cost of the process in the future. The time variable is used to introduce the aging effects on the energy cost estimation in order to increase the accuracy of the estimation. For this purpose, the evolution of energy costs will be assessed and modelled for a group of WWTPs using the methodology of cost functions. The results will be useful for the managers of the facilities in the decision making process.

1. Introduction

Water and energy are closely interconnected in the urban environment. Not only are they essential for the social and economic development of cities but also the production of one of them depends on the other (Hardy et al., 2012; King et al., 2008; Mo and Zhang, 2013; Perrone et al., 2011; Rio Carrillo and Frei, 2009). Recently the "water-energy nexus" has become more important given the pressure that the population growth has exerted on both resources (Healy et al., 2015; Pate et al., 2007; Siddiqi and Anadon, 2011), together with the high energy requirements of the urban water cycle (Cabrera et al., 2010) and the new energy policies implemented in this sector to reduce the greenhouse gas emissions (Frijns et al., 2012; Svensson et al., 2006). In a more recent study, Spiller (2017) develops a methodology to measure the capability of urban wastewater systems to adapt to what he calls "emerging changes", the reduction of the energy consumption being one of the changes that he mentions.

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Table 1
Sample description.

	2010		2011		2012	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Energy cost (€/year)	79,867	202,709	78,739	201,226	73,269	188,567
SS Removed (kg/year)	265,154	782,100	236,899	708,380	227,144	671,204
COD Removed (kg/year)	524,012	1,482,234	515,601	1,457,401	500,302	1,401,494
Treated Flow (m^3/year)	954,467	2,640,931	888,163	2,443,864	862,130	2,363,451
Design Flow (m^3/day)	4063	10,168	4063	10,168	4063	10,168
Equivalent inhabitants	13,326	38,395	13,089	37,908	12,876	36,839

Energy is essential in water resources management, as it allows water's exploitation but also maintains and guarantees the sustainability of the resource. The set of supply and sanitation infrastructures that make up the urban water cycle consists of large-scale energy consumers. Moreover, we can find considerable variations by country, generally associated with the availability of water resources, ranging from 1% in Sweden to 10% in Israel (Bodik and Kubaská, 2013).

The energy pattern of the urban water cycle is defined by the energy needs of the four stages that constitute it: 1) water collection and purification, 2) the drinking water supply system, 3) the sewage system, and 4) wastewater treatment and discharge. The energy consumption in the first phase of the cycle depends fundamentally on the nature of the water source: 0.37 kWh/m^3 for surface water and 0.48 kWh/m^3 for groundwater (WWAP, 2014). This difference is mainly due to the pumping system needed to push the groundwater to the surface. When the source is seawater, the energy consumption increases notably to 2.58 and 8.5 kWh/m^3, since the technologies used to treat this kind of water, such as membranes and osmosis, require a large amount of energy (WWAP, 2014). Then, regarding the drinking water system and the sewage network, Venkatesh et al. (2014) find that the energy consumption in the water supply system can range between 0.16 and 0.41 kWh/m^3, while the sewage system consumes much less, 0.03–0.13 kWh/m^3. These variations depend on the characteristics of the area served, the network design, and their management (Bolognesi et al., 2014). As far as the wastewater treatment process is concerned, the energy consumption and the operational cost of the Wastewater Treatment Plants (WWTPs) are influenced by the size of the plant, the quality parameters of the influent and the effluent, the kind of technology used, and the age of the equipment (Bodik and Kubaská, 2013; Corominas et al., 2013). It has been estimated that these technologies, used to implement the secondary treatment, consume 0.62–0.87 kWh/m^3 (WWAP, 2014). On the other hand, Longo et al. (2016) and Hernandez-Sancho et al. (2011b) claim that the implementation of technologies or mechanisms to remove either nutrients or pathogens from the wastewater increases the energy demand of the WWTPs, which could rise to 1.0–2.5 kWh/m^3 (WWAP, 2014).

In spite of the local variations in the energy consumption at the different stages of the urban water cycle, which depend not only on the volume and the quality of the water/wastewater treated but also on the service provided to the population (Venkatesh and Brattebø, 2011), we should be aware of the fact that wastewater treatment is one of the processes of the urban water cycle with higher energy requirements (Racoviceanu et al., 2007).

Table 2
Energy cost of the wastewater treated (€/m^3) for the period 2010–2012 and Kruskal-Wallis test result.\

Energy Cost (€/m^3)				
	2010	2011	2012	Kruskal-Wallis Test
Mean	0.11	0.14	0.15	0.001
Minimum	0.02	0.03	0.03	
Maximum	0.62	0.81	1.03	

There exist numerous technologies for the treatment of wastewater. One of the methods that are getting more attention nowadays on the grounds of the reduction of either operational or maintenance costs are constructed wetlands. However, their use is not widely spread yet, mainly for two reasons: the need of large extensions of land and the fact that they on both environmental and operational conditions, which could put at risk the quality of the effluent, since the characteristics of the wastewater can present large variations in quality and time (Fountoulakis et al., 2009; Vymazal, 2007; Vymazal and Kröpfelová, 2009). For this reason the current study is based on energy-intensive technologies such as extended aeration and activated sludge. According to the literature and the experience of the managers of WWTPs, a high percentage of the operating costs of the process are associated with energy (Guerrini et al., 2017; Hernandez-Sancho et al., 2011b; Torregrossa et al., 2017), which might represent between 25% and 56% of the operation and maintenance costs of the installation (Albaladejo and Trapote, 2013; Panepinto et al., 2016). Generally, more than a half of this energy is consumed by the biological treatment, due to the high energy requirement of the aeration systems of this phase (Brandt et al., 2011; Gikas, 2016; Sun and Li, 2010; Zhang et al., 2016). However, it should be noted that the energy consumption will depend on the characteristics of the plant, including the type of technology used, the size of the facility, and the contaminant load of the influent, among others (Plappally, 2012).

As a result, in recent years the reduction of energy consumption has been the main aim of wastewater treatment plant managers. One of the reasons for this is mainly economic, as a result of the rise in the energy tariffs (Bodik and Kubaská, 2013). There exist different factors that can affect the energy tariffs, such as the use of renewable resources in the production of energy which has increased recently up to 76% in Italy, 65% in Germany, and 17% in France, for instance (Eurostat, 2017); the existence of conflicts in different countries like Iraq; or even due to the interests or conflicts among the countries that are members of the Organization of the Petroleum Exporting Countries. For instance, some authors, including Albaladejo and Trapote (2013), show increases of up to 65.5% and 79.1% in the Spanish electricity tariffs during the period between 2009 and 2012, which had a significant impact on the cost structure of the WWTPs.

Table 3
Energy cost of the wastewater treated (€/m^3) differentiating two groups depending on the technologies applied for the period 2010–2012 and Kruskal-Wallis Test.

Energy Cost (€/m^3)				
	2010	2011	2012	Kruskal-Wallis Test
Group: T1				
Mean	0.117	0.145	0.150	0.001
Minimum	0.019	0.028	0.028	
Maximum	0.620	0.807	1.027	
Group: T2				
Mean	0.063	0.074	0.089	0.184
Minimum	0.033	0.046	0.038	
Maximum	0.132	0.154	0.164	