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EVALUATING THE ENERGY PERFORMANCE OF 20 PORTUGUESE WASTEWATER TREATMENT PLANTS

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Abstract *Wastewater treatment plants (WWTPs) perform a prominent role in minimizing adverse environmental and human health impacts by subjecting wastewater to proper treatment, which ensures the quality of the treated water before discharging or reusing. Due to the complexity and diversity of processes involved, WWTPs are regarded as energy-intensive facilities, with energy costs accounting the second largest share of their operating costs.*

Energy demand in this sector is expected to continue the growth shown in the last decades due to the increase in the number of people gaining access to improved sanitation facilities and to more stringent regulatory and environmental protection standards. Consequently, to ensure the sector's long-term sustainability it is essential to evaluate and improve the efficiency of the WWTPs using a holistic approach, by integrating environmental and economic features.

In this paper, data from 20 Portuguese WWTPs located at the North of Portugal were analysed to compare their energy performance. For this, some simple performance indicators are employed and the underlying factors affecting energy consumption are evaluated. From this study is possible to verify that, for the sampled WWTPs, population equivalent and size do not influence their energy requirements, while the presence of a primary treatment stage shows some influence. Moreover, it also shows that, despite allowing some interesting conclusions, comparing WWTPs should not be performed using only a few simple KPIs and must include other features that influence their process to avoid biased conclusions.

1. INTRODUCTION

Wastewater treatment plants (WWTPs) play an important role in minimizing adverse environmental and human health impacts by ensuring a suitable quality of the treated water. Thus, before discharge or reuse, wastewater is subjected to adequate treatment and can be submitted up to three treatment stages – primary, secondary and tertiary [1,2].

Due to the diversity and complexity of the processes involved, WWTPs are regarded as energy-intensive facilities [3,4], with energy representing one of the major costs of water and wastewater services. Usually, energy costs are only surpassed by the personnel costs, being the second largest portion of the running costs of a wastewater treatment plant [5]. Additionally, this energy dependence leads to the water sector being the main contributor to municipal energy use in developed countries, because water utilities, mainly municipality owned, account for almost 44% of municipalities' energy costs [4,5]. In developed countries, wastewater treatment exploits the largest share of water-related electricity consumption (42%), while in developing and emerging countries it exhibits a smaller portion, since a lower share of wastewater is currently collected and treated to lesser degree [1].

During the last decades, the number of people gaining access to improved sanitation facilities has increased substantially, which in turn has led to a considerable growth in the number of wastewater treatment plants operating throughout the world [6]. Moreover, coupled with the increase in the number of facilities, processes are expected to become more energy intensive due to several factors, such as increasingly stringent regulatory and environmental protection standards for effluent quality and water reuse, as well as the population growth and the corresponding increase in the contaminant load to be treated. Inevitably, energy demand in this sector is predicted to grow further in the coming decades [3].

Given the anticipated changes, and in order to ensure the sector's long-term sustainability, it is imperative to reduce the carbon footprint of these facilities, both environmentally and economically [3]. Thus, it is essential to evaluate the efficiency of the WWTPs using a holistic approach, by integrating environmental and economic features, to identify potential improvements at all stages, as well as to guarantee service quality, savings in operating costs, and proper environmental management of the water resources [6,7].

According to the literature [6–8], benchmarking the efficiency of WWTPs is considered a suitable approach for promoting their energy performance, since it allows to determine how the system works and which inputs and outputs are influencing their efficiency or inefficiency. Due to simplicity in implementation and interpretation, the normalization approach is generally used by plant operators, water companies and agencies, and all other stakeholders. This method is based on simple key performance indicators (KPIs) and single input and output ratios, such as the reporting of energy consumption in WWTPs referred to the volume of treated water (kWh/m^3) or unit of population equivalent (kWh/PE) on annual basis [7].

In this context, this paper presents the results of an energy performance assessment performed to a sample of 20 WWTPs located in the North of Portugal. In this analysis, some simple KPIs are employed, such as the energy consumption per volume of treated water, and the underlying factors affecting energy consumption are evaluated. Finally, the non-parametric

Kruskal-Wallis (K-W) test will be applied to confirm if the differences between the values are statistically significant.

2. FRAMEWORK AND METHODOLOGY

Data from 20 Portuguese WWTPs located in the North of Portugal were used to perform an evaluation of their energy performance, as well as to assess which factors may affect their energy efficiency. Figure 1 presents the annual energy consumption and volume of treated water for each of the facilities in the sample. As portrayed, both energy consumption and volume of treated water show quite different values among these facilities. Nonetheless, from this representation is not possible to establish a clear and thorough comparison between the facilities nor to examine their energy performance.

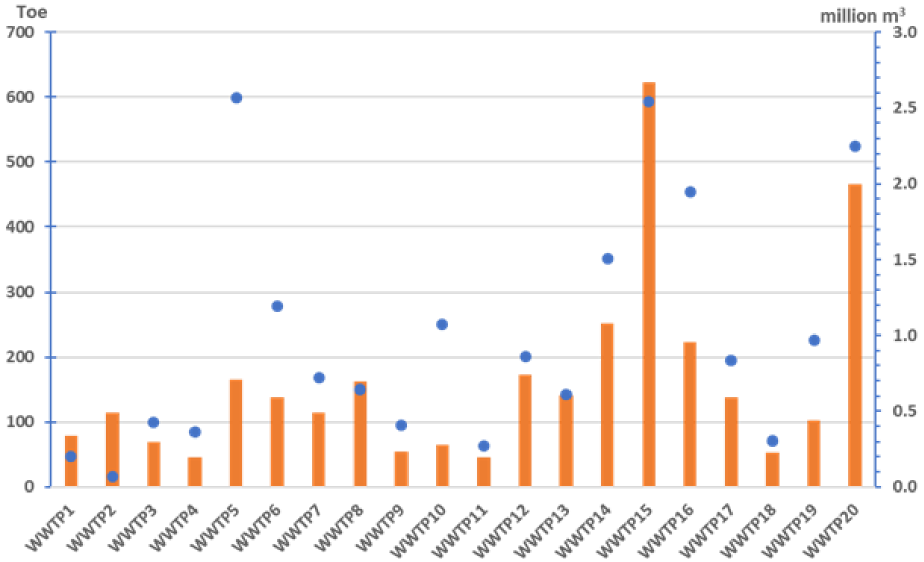

Figure 1. Energy consumption in tonnes of oil equivalent (bars) and volume of treated water (blue dots).

The analysis performed in this study was implemented in two stages. First, the annual data for the year 2017 of the twenty facilities was surveyed, such as energy consumption (kWh), volume of wastewater treated (m^3), total 5-day biochemical oxygen demand (BOD_5) mass removed (kg), and total chemical oxygen demand (COD) mass removed (kg). With this information, some KPIs were calculated by dividing energy consumption by the other characteristics.

According to the literature [1,2], energy requirements of WWTPs can be affected by several contextual factors. Thus, in a second phase, some factors, such as population equivalent, size and primary treatment stage, were considered to assess their effect. Then, using the *IBM SPSS 25*, the non-parametric test known as Kruskal-Wallis (K-W) will be applied to validate whether the observed differences between the values are statistically significant. The results are considered significant only if the p value is equal or smaller than 0.05.

3. RESULTS AND DISCUSSION

Typically, energy consumption per volume of wastewater treated is the indicator employed to evaluate energy consumption of WWTPs [8]. Thus, this is the first KPI calculated for the sample. However, it should be mentioned that this approach has one constraint that limits its application, since it is assumed that pollutant concentrations in the influent do not vary significantly between WWTPs or that effluent qualities are also similar [8].

In turn, reporting the energy consumption per unit of pollutant removed has the advantage that the removal of nutrients and organic matter have a large contribution for energy consumption in these facilities [8]. Consequently, the other KPI calculated are the energy consumption referred to BOD_5 mass removed and COD mass removed, respectively.

Figure 2 shows the values obtained for the three KPIs, namely energy consumption per volume of wastewater treated (green bars), energy consumption per BOD_5 mass removed (blue dots) and energy consumption per COD mass removed (red triangles).

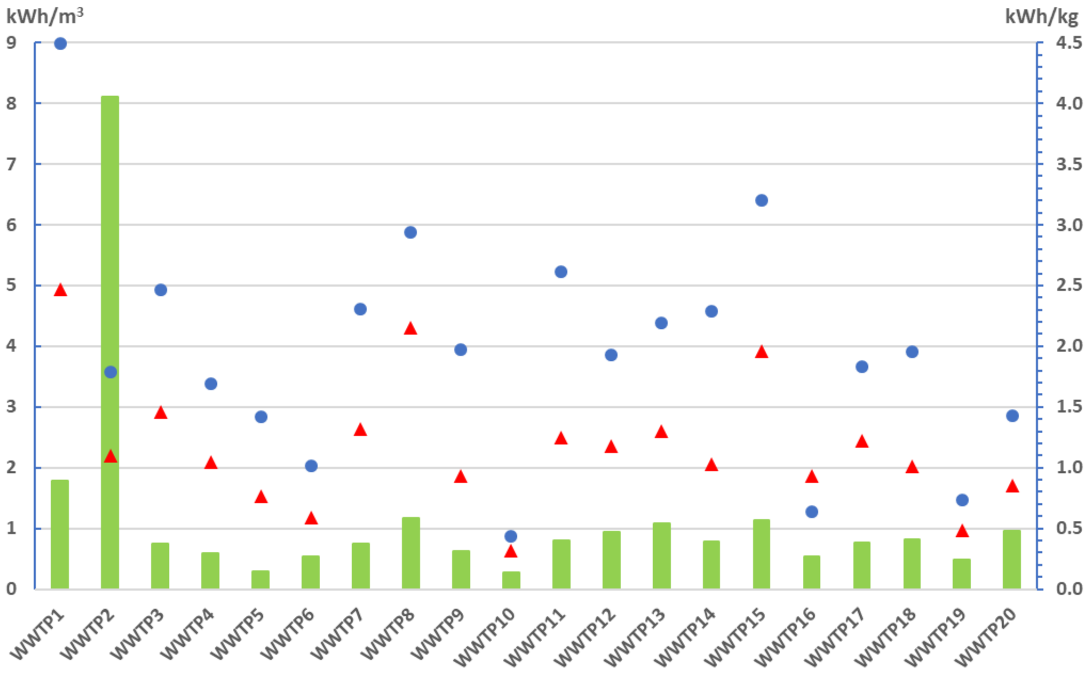

Figure 2. Representation of the values of the three KPIs.

As displayed, WWTP1 and WWTP2 present higher values of energy consumption per volume of wastewater treated compared to other facilities. Indeed, for WWTP2 this value is exceedingly higher, which may indicate inefficiency caused by several reasons, such as a reception flow much lower than the projected one or an inflow saturated with pollutants, since the values for the other indicators are in line with the other facilities. Regarding the other two KPIs, it is noticeable that the worse performances correspond to WWTP1, WWTP8 and WWTP15.

Finally, WWTP10 presents the lowest value for all three indicators, which implies that this WWTP presents the best performance of the facilities under analysis. Thus, it can be concluded that this facility is the most efficient of the 20 WWTPs, and that it should be considered a case study to help improving the efficiency of the other WWTPs in the sample.

Table 1 presents the results of the application of K-W test taking the three contextual factors into account. It is possible to notice that no statistically significant differences ($p<0.05$) were found when considering the population equivalent and size of the facilities. These results show that the two factors do not affect the energy performance of this sample. This conclusion is contrary to what could be expected, since studies in other countries point to the existence of economies of scale [6,7]. In turn, regarding the other factor, differences in values are statistically meaningful ($p<0.05$), revealing that the presence of a primary treatment stage influences the energy performance of these WWTPs.

Table 1. Results for the key performance indicators (KPIs).

		Nº WWTPS	Energy consumption/volume of wastewater treated			Energy consumption/BOD_5 mass removed			Energy consumption/COD mass removed		
			Mean	*SD*	*K-W test*	*Mean*	*SD*	*K-W test*	*Mean*	*SD*	*K-W test*
PE:	2000 - 9999	3	0.74	0.100	0.923	2.09	0.390	0.630	1.10	0.106	0.719
	10000 - 49999	13	1.39	1.974		2.03	0.985		1.19	0.580	
	> 50000	4	0.73	0.334		1.67	0.939		1.12	0.482	
Size (million m3/year):	< 0.5	7	1.93	2.554	0.607	2.42	0.901	0.382	1.32	0.493	0.495
	0.5 - 1.5	8	0.75	0.286		1.67	0.806		1.07	0.555	
	> 1.5	5	0.74	0.299		1.80	0.875		1.10	0.433	
Primary treatment stage:	Without	14	1.42	1.882	0.026	2.31	0.803	0.008	1.35	0.489	0.003
	With	6	0.56	2.554		1.16	0.901		0.73	0.493	

4. CONCLUSIONS

Benchmarking the efficiency of WWTPs is considered an adequate approach for evaluating their energy performance. As concluded in this study, the use of simple key performance indicators, such as energy consumption per volume of wastewater treated, allows the comparison of similar facilities and the achievement of some noteworthy conclusions. For the analysed sample, it was possible to conclude that the WWTP10 presents the best performance for all the considered indicators, while the WWTP2 presents an exceedingly higher value for the energy consumption per volume of wastewater treated, which may indicate a case of clear inefficiency.

From the application of the Kruskal-Wallis test, it was possible to verify that, unlike some studies in the literature, population equivalent and size (expressed in million m^3/year) do not influence the energy requirements of the sampled WWTPs. In turn, it clearly shows that the presence of a primary treatment stage influences the energy performance of these facilities. Overall, the study shows that comparing WWTPs should not be performed using only a few simple KPIs, but to include other features that influence their process, such as the organic matter and other substances in the wastewater, to avoid biased or incomplete conclusions.

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