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Energy and environmental performance of wastewater treatment plants: A statistical approach

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Abstract

Data of Portuguese wastewater treatment plants (WWTPs) were analyzed in order to compare their energy and environmental performances. Several absolute and ratio indicators were considered, namely, electricity consumption, CO_2 emissions from electricity, biochemical oxygen demand removal and the corresponding ratio indicators where each of the previous amounts was divided by total volume treated. Groups for statistical analysis were established considering different factors (population equivalent, size, etc.) and Kruskal-Wallis test was applied to assess the effect of these factors on the indicators considered. Significant differences were found for population equivalent and size for the three absolute indicators.

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*Keywords:*Energy; environment; statistics; sustainability;WWTP

1. Introduction

Modern societies rely on wastewater treatment plants (WWTPs) in order to reduce contamination from households and industries and therefore assure environmental quality standards. WWTPs are intended to reduce certain chemical parameters such as organic carbon or nutrient loads, but usually little attention was given to energy efficiency [1]. However, as the number of WWTPs increases and the effluent quality requirements become more demanding, the issue of energy efficiency has been attracting increasing attention from an environmental and economic point of view [2]. Despite the obvious benefits of WWTPs, they also have environmental impacts such as

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eutrophication and contributions to climate change [3].

WWTPs are relevant energy consumers, not only onsite, namely the electricity used for pumping and aeration, but also offsite, for producing and transporting chemicals for treatment. Energy is therefore an important cost factor in wastewater treatment, being generally the second one after personnel costs [4].

Optimization of energy consumption, efficiency of design and of equipment and technology operations, energy recovery processes, and good management of energy pricing are being increasingly considered in the field of water treatment [4].

Recent reviews on the comparison of WWTPs energy performance revealed three main benchmarking approaches: normalization, statistical techniques and programming techniques, although the diagnosis of the individual WWTP energy performance remains an unsolved issue. Plant size, dilution factor and flowrate seem to be the variables that have the largest effect on energy consumption [2].

For a sample of 60 Spanish WWTPs, the population equivalent treated was the only factor affecting the environmental performance indices proposed, and facilities employing anaerobic digestion for sewage sludge exhibited the best environmental performance [3].

Average energy consumption per cubic meter of wastewater treated does not differ much across countries, despite technology differences, ranging from 0.36 kWh/m^3, in the Netherlands, to 0.67 kWh/m^3, in Germany [4]. Independently of WWTP size, most of the energy is consumed in biological treatment. Additionally, plants with lower treatment capacity use more energy than larger plants [4].

In recent years the concept of "eco-efficiency" has been universally recognized as a component of sustainability, since it is defined as a ratio of economic value added to environmental damage. A number of alternative measures or indicators have been suggested to assess the eco-efficiency of different types of organizations, ranging from simple indicators to more sophisticated ones [3].

Lorenzo-Tojas et al. have analysed the eco-efficiency of 113 WWTPs located in different regions across Spain. Large inefficiencies were observed related to several reasons such as climatic characteristics, the load of the influent or the complexity of the treatment technology. Nevertheless, higher efficiency levels were attained with increasing operational size [5].

In this study data from 13 Portuguese WWTPs presented by Alves [6] were analyzed in order to compare the energy and environmental performance of the WWTPs. Several indicators were used, either absolute (electricity consumption, CO_2 emissions calculated from electricity consumption, biochemical oxygen demand (BOD) removed) or relative, as the ratio to the total effluent volume treated. Groups were established considering different factors (population equivalent, size, etc.) and statistical analysis using the Kruskal-Wallis test was performed in order to assess the effect of these factors.

2. Methods

In this work, data from 13 Portuguese WWTPs presented by Alves [6] were used to carry out an analysis to determine which factors affect electricity consumption and environmental performance of WWTPs. The first step was to establish the indicators either absolute or ratios that are relevant to WWTPs performance, then a set of factors that could affect the indicators were selected according to the characteristics of the different WWTPs. Finally, a non-parametric test known as Kruskal-Wallis was applied.

2.1. Indicators

The absolute performance indicators considered in this study are electricity consumption, CO_2 emissions from electricity consumption, BOD removed and the three ratio indicators are the previous amounts divided by total volume treated, in m^3.

The emissions of carbon dioxide were estimated taking in consideration the emission factor given in the Portuguese legislation (Despacho nº 17313/2008 of 26 of June), which indicates a value equal to 0.47 $kgCO_2$/kWh. However, considering the electricity mix for Portugal for the year of data collection and using SimaPro, the emissions would be around 20% higher.

The indicators considered and their respective units are presented in Table 1.