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Environmental performance of wastewater treatment plants for small populations

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Abstract

Life cycle assessment (LCA) is an environmental tool which allows the calculation of all the environmental loads related to a process/product/service. In the present work, LCA was applied to analyze the environmental impact of different technologies for wastewater treatment in small populations. In this study, 13 wastewater treatment plants (WWTPs) of less than 20,000 population equivalent (p.e.) located in Galicia (NW Spain) were inventoried. The results of the evaluation of the environmental impact are expressed in terms of diverse impact categories. Normalization identified eutrophication, mainly as P-PO_4^{3-}, N-NH_4^+ and organic load as chemical oxygen demand (COD) in the treated effluent, and terrestrial ecotoxicity, due to the heavy metals content in the sludge, as the most significant categories for all WWTPs. Electricity use plays an important role in five of seven impact categories and presents the highest importance in four of them. When comparing technologies, secondary treatment technologies such as biodenipho and aerobic–anoxic treatment resulted in a lesser environmental impact than extended aeration. The operation of the plants has large contribution on the impact, especially for those that make use of extended aeration.

Keywords: LCA; Life cycle assessment; Wastewater treatment plants; Eutrophication; Terrestrial ecotoxicity; Electricity use

1. Introduction

Nowadays, society demands that all processes, product or services must be also analyzed from an environmental point of view, including those that are considered for emissions treatment, such as wastewater treatment plants (WWTPs). In these systems a variety of processes take place: energy is consumed, chemical reagents are used, and sludge and environmental emissions are derived. Therefore, it is necessary to analyze the system to determine the overall pollution associated to these activities.

One of the main challenges for European water authorities is wastewater treatment policies in small villages. In fact, the European Directive 91/271 states that by 1st January 2006, all generated emissions from populations between 10,000 and 15,000 population equivalents (p.e.) must be treated in facilities with secondary treatment, except in coastal zones, where only primary treatment is compulsory. This fact justifies the environmental study of different applied technologies in villages with small numbers of inhabitants.

Life cycle assessment (LCA) is a technique for assessing environmental parameters and the potential impact associated with a product/process/service by means of three actions: the compilation of an inventory of relevant inputs and outputs of a product system; the evaluation of the potential environmental impact associated with those inputs and outputs; and, the interpretation of the results of the inventory analysis and impact assessment phases in relation to the objectives of the study (Baumann and Tillman, 2004).

There are several previous LCA studies on wastewater treatment. Lassaux et al. (2007) recently studied the anthropogenic cycle of water from pumping stations to WWTPs in the Wallon Region (Belgium). The chosen functional unit was a cubic meter of water. They concluded that the more wastewater treated the less the global impact. Along the cycle, the stages that contributed most to the impact were the following: water discharge,

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WWTP operation and, to a lesser extent, construction of the sewage system network.

Some references are available in relation to small city centers. In Sweden, Tillman et al. (1998) and Lundin et al. (2000) applied LCA for the evaluation of traditional wastewater treatments as well as possible alternatives in small towns (between 200 and 12,600 p.e.). In both cases, the functional unit selected was the treatment of wastewater associated with 1 p.e./year. Both studies concluded that the impact associated with construction was minor, relative to the associated operation. When different technologies were compared, only one of the proposed alternatives was environmentally safer in all impact categories considered; in the others, the recommended options depended on the categories of interest.

On the other hand, Kärrman and Jönsson (2001) presented a method to standardize the environmental impact of four systems of wastewater treatment, quantifying their contribution to the total impact of the Swedish society. The functional unit used was wastewater treatment associated with 20,000 p.e./year. Construction of the facilities was not considered. Wastewater treatment was found to contribute with more than 10% of the total impact regarding specific aspects such as discharge of nitrogen, cadmium, lead and mercury and heavy metal uptake in soil.

In Spain, the first approach to this subject was made by Vidal et al. (2002), who compared biologically active sludge treatment in a WWTP of 22,167 p.e. with two configurations specifically designed for nitrogen removal (oxidation channel and Ludzack-Ettinger). The functional unit was one ton of treated wastewater. Eutrophication was largely improved when the proposed alternatives were considered. However, both of them implied larger energy requirements, which led to greater impact in the rest of categories. Even so, the global impact related to these two configurations was smaller than that of activated sludge, with the oxidation channel being the best alternative.

The aim of the study presented here is to assess different alternatives for small WWTPs in order to establish which one is the most adequate in terms of minimum environmental impact. The paper will be presented according to the four main phases in LCA: goal and scope definition, inventory analysis, impact assessment and interpretation of the results.

2. Goal and scope definition

During this phase, the purpose of the LCA study is defined and specifications on the LCA model and procedure are determined (Baumann and Tillman, 2004).

2.1. Objectives

Galicia (NW of Spain) is characterized by the existence of a huge amount of low-populated locations; in fact, according to the last census (year 2006) more of 93% of the municipalities have less than 20,000 inhabitants, stating for almost 50% of the population of the region (INE, 2007). This distribution made it the right place to evaluate the environmental performance of WWTPs in small villages (less than 20,000 p.e.).

The most relevant factors contributing to the overall environmental impact will be identified. The analysis of different existing treatment technologies (biodenipho, aerobic–anoxic and extended aeration) will help to establish which technologies should be considered as the most adequate to implement from an environmental point of view. The influence of the operation on the environmental impact will be also evaluated.

2.2. Functional unit

The functional unit expresses the function of the product or service under evaluation in quantitative terms and serves as basis for the calculations. It is the reference flow to which all other flows in the LCA model are referred. It also serves as a unit of comparison in comparative studies (Baumann and Tillman, 2004).

The main function of a WWTP is the treatment of an influent (with the objective of organic load, nutrient and suspended solids reduction) so as to reach satisfactory values before release in natural water courses.

In order to refer to the functional unit as the volume of the influent and its associated load, this factor was defined in terms p.e., in the same line that other research works (Tillman et al., 1998; Lundin et al., 2000; Kärrman and Jönsson, 2001).

2.3. System

Each WWTP was divided in 4 subsystems (Fig. 1): pretreatment and primary treatment (subsystem 1), secondary treatment (subsystem 2), sludge line (subsystem 3) and transport and sludge use (subsystem 4). All subsystems include consumption of electricity and chemicals, that is to say, their production and transportation upstream, as well as the transport and treatment downstream of the sludge and other waste generated in the WWTPs. Table 1 gives a detailed description of the subsystems for each WWTP.

From the technological point of view, the most remarkable difference is the type of technologies used for secondary treatment (Fig. 2), and to a lesser extend the type of units used for sludge dehydratation (centrifuges or filter band). In particular, three different secondary treatments are presented (Metcalf and Eddy, 2001):

- Extended aeration: the reactor is equipped with mechanical aeration and mixing devices. Screened wastewater enters the reactor and is combined with the return activated sludge. The tank configuration and aeration and mixing devices provide unidirectional reactor flow, so that the energy used for aeration is sufficient to provide mixing in a system with a relatively long hydraulic retention time.
- Biodenipho: influent wastewater is initially mixed with the return activated sludge in the anaerobic selector prior to being directed to two oxidation ditches placed in series. The operating sequence of the ditches and operation of the aeration and anoxic zones is varied. Submerged mixers are installed in the ditches so that for some operating phases, the basin is only mixed and not aerated. The basin continues to receive