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Assessing wastewater treatment in Latin America and the Caribbean: Enhancing life cycle assessment interpretation by regionalization and impact assessment sensibility

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ABSTRACT

Life cycle assessment (LCA) was applied to evaluate two wastewater treatment plant (WWTP) scenarios in Latin America and the Caribbean (LAC): extended aeration (EA) and pond system (PS). The main goal was to compare the environmental performance of two WWTP technologies across all environmental impact categories in selected methods when developing new WWTP projects. As a complementary goal, we analyzed how regionalization enhances LCA interpretation through a case study illustrating the spatial variability of WWTP results for 22 Latin American and Caribbean countries.

A generic LCA relying on averaged primary data from 158 WWTPs was first performed based on three LCIA methodologies: ReCiPe, IMPACT World+ (IW+) and Impact 2002+. The results were used to identify the parameters that most influence the impact scores and test the sensitivity of the choice of LCIA methodology on the conclusions. While EA is the most impactful scenario for the human health (HH) and ecosystem quality (EQ) indicators according to Impact 2002+, ReCiPe considers it to be the least impacting option. This is mainly due to the fact that ReCiPe includes the contribution of global warming impacts at the damage level whereas IMPACT 2002+ does not. For the same reason, IW+ favours EA for the HH indicator, which is dominated by global warming impacts. However, for EQ, the PS scenario scores better because of the lower relative importance of global warming impacts (GWP) as compared to eutrophication impacts (FE) at the damage level. Both the IW+ and ReCiPe methodologies point to a trade-off between the two impact categories, which dominate the impact scores for this area of protection. A sensitivity analysis was therefore carried out at the inventory level considering regional grid electricity mixes and at the impact assessment level characterizing eutrophying emissions from WWTPs with the regional CFs for the 22 LAC countries provided by the IW+ model. Results from the IW+ analysis showed that the operating conditions of WWTP in countries where 43–80% of electricity is produced from fossil fuel tend to favour PS for the EQ and HH damage categories. Operating conditions in countries with an electricity mix of over 60% hydropower favour EA due to the significant decrease in greenhouse gas emissions for the EQ and HH damage categories. The location where a WWTP operates also influences the results of the impact assessment. For example, locations with higher eutrophication characterization factors such as Brazil, where the residence time of water is higher, do not tend to favour scenarios with higher eutrophying emissions such as EA with higher EQ impact scores as compared to PS. We concluded that regionalization, both of the inventory and characterization factors, show the potential for adding relevance and discriminating power to the LCA. To address regionalization it in standard LCA practice we propose a pragmatic and stepwise iterative approach that makes it possible to regionalize the greatest contributing inventory and the most impactful assessment flow. Nevertheless, it is important to note that we only addressed the uncertainty related to known spatial variability and that it may be of major interest to apply a similar stepwise approach to any other type of uncertainty.

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1. Introduction

With approximately one-third of the world's water resources and 24 400 m^3 of water per capita per year (WB, 2014a), Latin America and the Caribbean (LAC) is a region with high freshwater resource availability (ECLAC/UNW-DPAC, 2012). However, only 20% of municipal wastewater is treated (Balcazar, 2008). Also, according to a survey by Noyola et al. (2012), the majority (38%) of wastewater treatment plants (WWTPs) in LAC are stabilization ponds (based on the number of facilities). However, activated sludge (mostly conventional and extended aeration) treats the higher accumulated sewage flow that enters the LAC treatment facilities (58%).

Given the infrastructure lag in LAC and the investments required to build new facilities, the determination of treatment systems for sustainable wastewater management is highly relevant and opportune. Furthermore, in most LAC countries, many treatment facilities are abandoned due to high operating costs or underperformance. Making the right decisions in this growing sector brings added value by reducing the associated environmental impacts.

A WWTP aims to remove pollutants from sewage in order to produce effluents that may be discharged or reclaimed with reduced environmental impacts according to local or national discharge standards. However, treatment technologies produce sludge, can generate gaseous emissions and consume electricity and chemicals, which all result in environmental burdens. In other words, a WWTP leads to environmental impacts that vary in magnitude depending on different factors, including the choice of treatment technology, the sensitivity of the stream that receives the treated water and the atmospheric fate and deposition for emissions to air environments. Technology selection must take into account aspects related to investment and operating costs, as well as the environmental impacts arising out of facility operations. Life cycle assessment (LCA) was applied to support responsible decision-making processes. LCA is a comprehensive environmental assessment tool that quantifies potential impacts over the entire life cycle of a product, service or process to minimize the risk of burden shifting across life cycle stages or environmental issues. The LCA methodology is subdivided into four stages (ISO, 2006): goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and results interpretation.

In the LCIA stage, the potential environmental impacts of each inventory emission are quantitatively modeled according to relevant environmental mechanisms using a characterization model (Hauschild et al., 2013). Several LCIA methodologies, some of which still share some modeling assumptions, are integrated as different methods, and the final results may therefore be influenced. According to Noyola et al. (2012), decision-making processes involve many factors, such as community acceptance, area required, costs, design, construction, lifespan, waste and sludge generation and environmental impact. Because the project aimed to conduct an environmental LCA study, the social, cost and siting aspects were not considered. However, they are discussed for the LAC region in Noyola et al. (2013).

We identified 46 publications on wastewater treatment and LCA. Used in 16 studies, CML is the most prevalent method. Another sixteen publications did not specify the impact assessment methodology that was used. Five European studies carried out comparisons using more than one LCIA method (see Table 1A in Appendix A). In total, 27 European studies used methods that corresponded to their geographic area. However, two non-European surveys (Foley et al. (2010) in Australia and Cornejo et al. (2013) in Bolivia) did not use methods with adequate geographical parameterization for the regions in which they were applied. Moreover, the wastewater treatments analyzed in the studies considered nutrient removal, which still is not a reality in most municipal plants in the LAC region (Jimenez and Asano, 2008).

Blanc and colleagues (Blanc et al., 2010) recognized regionalization (related to inventory and methods) as an important step in improving the accuracy and precision of LCA results, increasing their discriminatory power for comparative assessments among different scenarios. However, there is no published case study showing how regionalization can be made operational in LCA practice using a regionalized impact assessment methodology and optimizing regionalized data collection with a systematic iterative approach.

We found that 45 of these studies collected primary emissions data on site and used generic characterization factors. Only Lehtoranta et al. (2014) used Finland-specific characterization factors (for P, N, and NH3) for impacts on freshwater eutrophication. Until 2013, the characterization factors (CFs) for eutrophication in current LCIA methodologies did not consider the specificities of different locations (Corominas et al., 2013a) but certain methodologies (e.g. Lime (Japan), TRACI (US) and LUCAS (Canada), etc.) were developed to consider regional features. Moreover, some studies incorporated spatially differentiated CFs to assess EP in France (Basset-Mens et al., 2006), Spain (Gallego et al., 2010) and the US (Norris, 2002) but these methods and studies may not be valid in the geographic context of the LAC region. To fill this gap is IW+, which develops regionalized CFs consistently at the global scale.

To the authors' knowledge, Cornejo et al. (2013) published the only LCA study on WWTPs in a LAC country. They compared an upflow anaerobic sludge blanket reactor (UASB) complemented by two maturation ponds and a facultative pond combined with two maturation ponds in series and applied an LCIA. However, they used a European method that may not be relevant to the LAC context without any regional adaptation for impact assessment.

This study aims to compare the two most common WWTP scenarios in LAC: activated sludge in extended aeration (EA) variant and the stabilization pond system (PS). To our knowledge, activated sludge and stabilization ponds without nutrient removal have not been assessed for LAC with an adequate LCIA methodology adapted to the regional context. In this sense, this study fills the gap. The results are intended to support environmentally responsible decision-making in order to favour the least impacting technology when implementing a new WWTP project. As a complementary goal, we aim to operationalize a regionalized methodology to enhance the interpretation of LCA through a case illustrating the spatial variability of WWTP results for 22 Latin American and Caribbean countries.

2. Material and methods

2.1. Descriptions of the systems

Representative configurations of WWTP scenarios in LAC were selected according to findings by Noyola et al. (2012) based on a sample of 2774 WWTPs in six LAC countries (Brazil, Chile, Colombia, Guatemala, Mexico and the Dominican Republic). Noyola et al. (2012) classified the WWTPs into four sizes: small (0–25 L/s), medium (25.1–250 L/s), big (250.1–2500 L/s) and huge (>2500 L/s). They found that small WWTPs are very common in LAC, even in big cities, and that these facilities represent 67% of the sample (1842 of 2774 facilities). This study therefore focuses on small WWTPs, whose average representative flow was calculated as 13 L/s according to the statistical measure of central tendency, the truncated mean of 1657 (5% trimmed mean from the top and the bottom). Moreover, for comparison purposes, the two most common treatment systems in LAC were considered: stabilization ponds (SP) and

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