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Including Life Cycle Assessment for decision-making in controlling wastewater nutrient removal systems

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ABSTRACT

This paper focuses on the use of Life Cycle Assessment (LCA) to evaluate the performance of seventeen control strategies in wastewater treatment plants (WWTPs). It tackles the importance of using site-specific factors for nutrient enrichment when decision-makers have to select best operating strategies. Therefore, the LCA evaluation is repeated for three different scenarios depending on the limitation of nitrogen (N), phosphorus (P), or both, when evaluating the nutrient enrichment impact in water bodies. The LCA results indicate that for treated effluent discharged into N-deficient aquatic systems (e.g. open coastal areas) the most eco-friendly strategies differ from the ones dealing with discharging into P-deficient (e.g. lakes and rivers) and N&P-deficient systems (e.g. coastal zones). More particularly, the results suggest that strategies that promote increased nutrient removal and/or energy savings present an environmental benefit for N&P and P-deficient systems. This is not the case when addressing N-deficient systems for which the use of chemicals (even for improving N removal efficiencies) is not always beneficial for the environment. A sensitivity analysis on using weighting of the impact categories is conducted to assess how value choices (policy decisions) may affect the management of WWTPs. For the scenarios with only N-limitation, the LCA-based ranking of the control strategies is sensitive to the choice of weighting factors, whereas this is not the case for N&P or P-deficient aquatic systems.
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1. Introduction

Decisions about wastewater nutrient removal systems have traditionally been driven by considerations of technical aspects and cost-benefit analyses. In order to assess sustainability it is essential also to incorporate environmental and social aspects. In this line, several methods for sustainability assessment of wastewater treatment technologies have been proposed and evaluated in literature (e.g. Muga and Mihelcic, 2008; Guinée et al., 2011). Focussing on environmental performance, Life Cycle Assessment (LCA) (ISO 14040, 2006) is an accepted tool that has also been used to evaluate potential environmental impacts from environmental processes (Finnveden et al., 2009) including wastewater treatment processes throughout their whole life cycle (Guest et al., 2009; Kalbar et al., 2012). The success of this method is demonstrated by the large number of published studies which have applied LCA to the wastewater treatment field (Corominas et al., 2013). The published studies so far, have been applied to estimate the impact of different wastewater treatment plants (WWTPs) and to compare conventional and new wastewater treatment technologies.

Complex wastewater nutrient removal systems require sophisticated monitoring and control systems that optimize overall process performance and account for daily and seasonal process variability. The optimization of treatment technologies dealing with nitrogen and phosphorus removal has never been evaluated in terms of environmental performance using LCA, probably because of the technical difficulty of evaluating multiple strategies at full scale. An alternative to intensive full-scale optimization is the use of models. These, are cost-effective tools for the evaluation of control strategies as has been demonstrated by the IWA Task group of benchmarking of control strategies (Gernaey et al., 2013).

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Hence, the combination of mechanistic models for evaluating control strategies with LCA tools can bridge the gap between process control and environmental performance (Flores-Alsina et al., 2010).

Linking LCA results with decision-making is a challenging task. First, LCA has traditionally been a site and time-independent/generic tool and for impact categories such as global warming (GW) a site-generic approach is justifiable. However, other impact categories are site-dependent (e.g. nutrient enrichment, NE) and the generic models most probably provide a far from realistic description of the impacts. Therefore, LCA research is moving towards developing methodologies that include the importance of local conditions and set country-specific or site-dependent characterization factors (e.g. Gallego et al., 2010; Basset-Mens et al., 2006; Azevedo et al., 2012). Second, LCA methodology proposes a weighting step, which allows for consideration of the relative importance of the different impact categories. Most studies present the results without weighting leaving the final interpretation to the decision-maker. We believe that incorporating an evaluation of the importance of the weighting factors in the discussion of the LCA results would facilitate the task of the decision-makers.

The goal of this paper is to present a methodology to evaluate the environmental impacts of enhanced process performance strategies applied to wastewater nutrient removal systems. The assessment of site-specific conditions for the NE impact category and the assessment of the importance of weighting factors are key issues addressed in this paper.

2. Process and nutrient removal strategies description

2.1. Process

The Neptune Simulation Benchmark (NSB) is the virtual WWTP under study (Fig. 1) which serves 80,000 population equivalents and comprises the water treatment and the sludge treatment lines. The design of the water treatment line was conducted following the Metcalf & Eddy guidelines (Tchobanoglous et al., 2003). First, there is a primary settler of 900 m^3, which reaches on average 50% TSS removal. Then, biological treatment was designed for an average flow rate of 22,938 m^3 d^{-1} and organic, nitrogen and phosphorous loads (just after primary settling) of 12,200 kg COD d^{-1}, 1140 kg N d^{-1} and 215 kg P d^{-1} respectively. The biological treatment configuration is the A$_2$O (Tchobanoglous et al., 2003) comprised of seven reactors in series (tank An1 & An2 are anaerobic with a volume of 1000 m^3 each, tanks Ax1 and Ax2 are anoxic with a volume of 1500 m^3 each and tanks Ox1, Ox2 and Ox3 are aerobic with a volume of 3000 m^3 each). Ax1 and Ox3 are linked by means of an internal recycle of 108,000 m^3 d^{-1}. The system allows for the addition of chemicals to improve nitrogen and phosphorus removal. Sodium acetate can be added in An1 when carbon source is a limiting factor for denitrification and phosphorus removal. Ferric chloride can be added in Ox3 to promote the precipitation of phosphorus. The secondary settler has a surface area of 1500 m^2 and a total volume of 6000 m^3. Part of the settled sludge is recycled to An1 (22,600 m^3 d^{-1}) and part is wasted (400 m^3 d^{-1}) for further

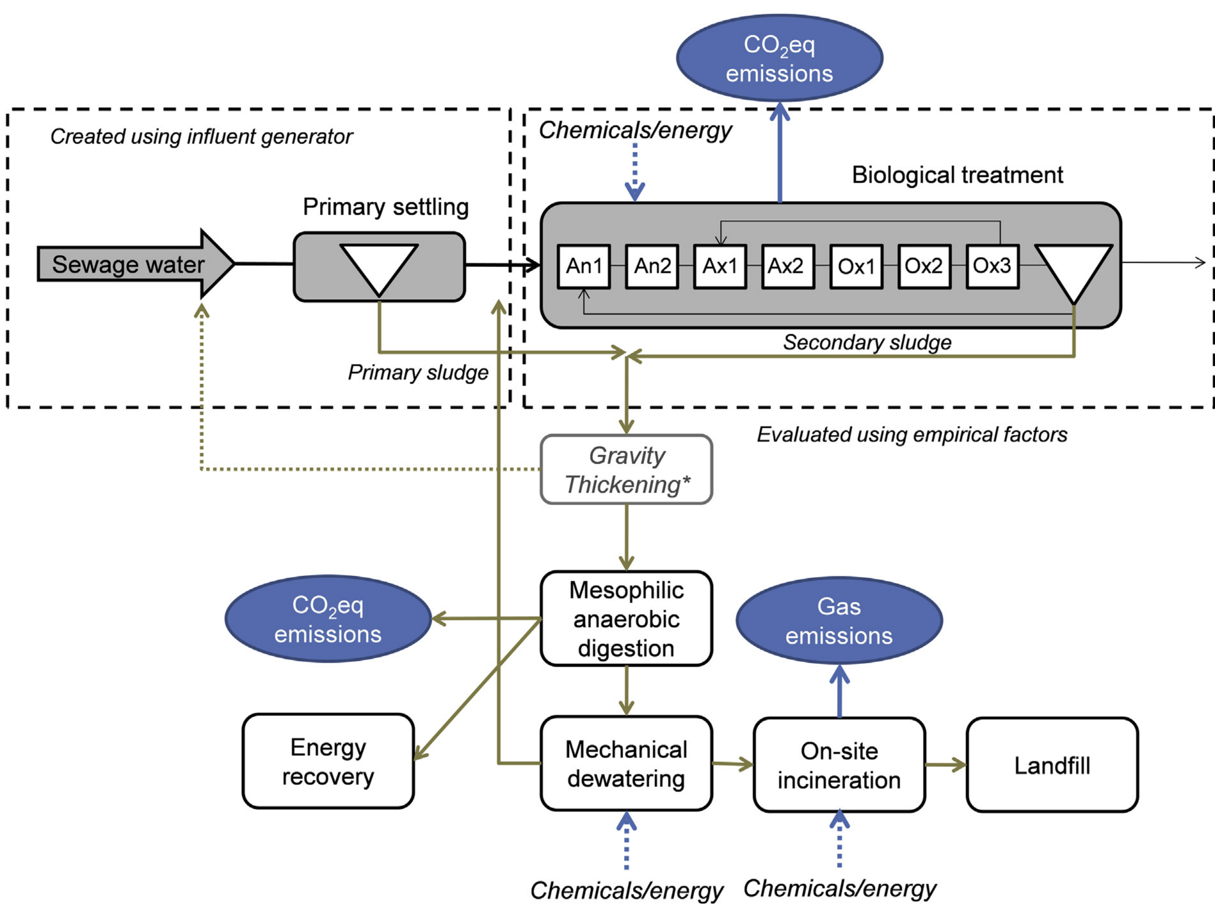

Fig. 1. Neptune simulation benchmark process schematic. Grey boxes correspond to a deterministic dynamic model and white boxes to simplified model using empirical factors. *Gravity thickening is assumed not to have a significant impact on the LCA results and is therefore not included in the evaluation.

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