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Beyond the conventional life cycle inventory in wastewater treatment plants

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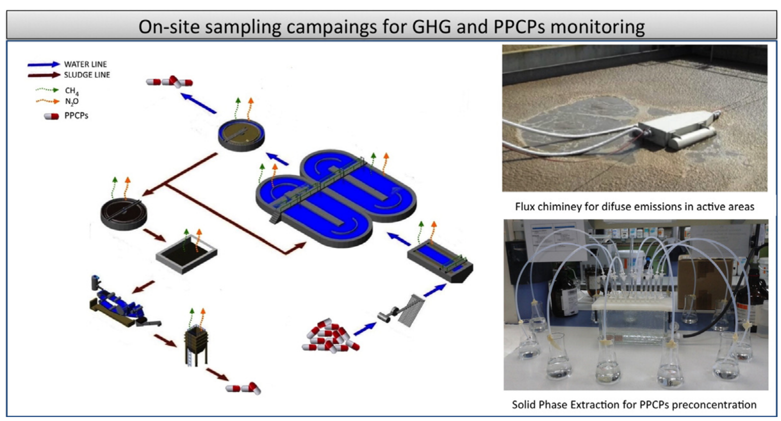
HIGHLIGHTS

- The influence of LCI quality on the environmental assessment of a WWTP was measured.
- Data obtained through on-site measurements in two sampling campaigns.
- Sampling campaigns were based on seasonality in two different WWTPs in Spain.
- GHG direct emissions appeared to be highly relevant for the overall GWP of a WWTP.
- Inclusion of PPCPs in the LCI is relevant for freshwater ecotoxicity assessment.

GRAPHICAL ABSTRACT



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ABSTRACT

The conventional approach for the environmental assessment of wastewater treatment plants (WWTPs) is typically based on the removal efficiency of organic load and nutrients as well as the quantification of energy and chemicals consumption. Current wastewater treatment research entails the monitoring of direct emissions of greenhouse gases (GHG) and emerging pollutants such as pharmaceutical and personal care products (PPCPs), which have been rarely considered in the environmental assessment of a wastewater treatment facility by life cycle assessment (LCA) methodology. As a result of that, the real environmental impacts of a WWTP may be underestimated.

In this study, two WWTPs located in different climatic regions (Atlantic and Mediterranean) of Spain were evaluated in extensive sampling campaigns that included not only conventional water quality parameters but also direct GHG emissions and PPCPs in water and sludge lines. Regarding the GHG monitoring campaign, on-site measurements of methane (CH_4) and nitrous oxide (N_2O) were performed and emission factors were calculated

Abbreviations: CAS, conventional activated sludge; CFs, characterisation factors; COD, chemical oxygen demand; EP, eutrophication potential; FETP, freshwater ecotoxicity potential; FU, functional unit; GC/MS/MS, Gas Chromatography coupled with Mass Spectrometry; GHGs, greenhouse gases; GWP, global warming potential; HTP, human toxicity potential; LCA, life cycle assessment; LCIA, life cycle impact assessment; LCI, life cycle inventory; LC/MS/MS, Liquid Chromatography coupled with Mass Spectrometry; METP, marine ecotoxicity potential; NEB, net environmental benefit; ODP, ozone layer depletion; p.e, population equivalent; PPCPs, pharmaceutical and personal care products; SRT, sludge retention time; TKN, total Kjeldahl nitrogen; VS, volatile solids; WWTPs, wastewater treatment plants.

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(PPCPs)
Wastewater treatment

for both WWTPs. GHG direct emissions accounted for 62% of the total global warming potential (GWP), much more relevant than indirect CO_2 emissions associated with electricity use.
Regarding PPCPs, 19 compounds were measured in the main streams: influent, effluent and sludge, to perform the evaluation of the toxicity impact categories. Although the presence of heavy metals in the effluent and the sludge as well as the toxicity linked to the electricity production may shade the toxicity impacts linked to PPCPs in some impact categories, the latter showed a notable influence on freshwater ecotoxicity potential (FETP). For this impact category, the removal of PPCPs within the wastewater treatment was remarkably important and arose as an environmental benefit in comparison with the non-treatment scenario.

1. Introduction

Since the first studies reported in the 90s, the environmental assessment of wastewater treatment plants (WWTPs) has been bounded to the life cycle assessment (LCA) methodology. LCA has evolved along these two decades in order to fulfil the new concerns within wastewater treatment. Thenceforward until now, numerous studies have been published in international journals using different inventories, boundary conditions, functional units and impact assessment methods for results computation of the urban water cycle. Corominas et al. (2013) in their literature review on LCA and wastewater highlighted the relevance of including priority substances and the role of greenhouse gases (GHG) when analysing LCA impacts from WWTPs. Moreover, Yoshida et al. (2013) showed the influence of the sludge treatment technologies and final disposal in LCA results.

LCA studies of end-of-pipe technologies such as WWTPs aim at computing environmental emissions from all the involved processes, gathered in the LCI and converting them into environmental impacts and indicators (Yoshida et al., 2014). Data collection and LCI build-up are crucial stages when performing an LCA study and usually limited by the availability of reliable data (Finnveden, 2000). The possibility of performing on-site measurements to reduce data uncertainty is frequently prohibitively expensive or even not feasible (Reap et al., 2008). One important fact that helps in data collection is that in the framework of mandatory regulations, WWTPs already monitor water and sludge quality parameters for periodic report to authorities. However, these periodic reports only present conventional operational parameters about the composition of influent and effluent while the assessment of GHG emissions or pharmaceutical and personal care products (PPCPs) are out of the scope.

Municipal WWTPs have been found as relevant emission sources of GHG; in particular, methane (CH_4) and nitrous oxide (N_2O) (Ahn et al., 2010; Daelman et al., 2015; Foley et al., 2010a; Hofman et al., 2011; Kampschreur et al., 2009). The main efforts in the quantification of direct GHG emissions are performed by monitoring CH_4 and N_2O which present global warming potentials (GWP) of 28 kg CO_2 eq and 265 kg CO_2 eq per kg of compound emitted, respectively (Stocker et al., 2013). Both GHG are produced within the WWTP in different locations and environments. Concerning CH_4, the main sources are those units where anaerobic conditions prevail, such as sludge thickeners and sludge storage tanks (Daelman et al., 2012). Nonetheless, another important source of CH_4 is the sewer system (Guisasola et al., 2008). Thus, CH_4 is not only emitted in the units where it is produced but also in aerated areas via stripping (Daelman et al., 2013b). Regarding N_2O, it has been mainly reported in anoxic zones of activated sludge configurations where nitrification and de-nitrification reactions lead to the production of N_2O (Kampschreur et al., 2009; Ahn et al., 2010). Additionally, some studies also point out N_2O emissions in de-griter units, presedimentation tanks, secondary clarifiers as well as sludge line units (Czepiel et al., 1995).

Another contemporary concern is the presence of emerging pollutants in sewage (Ternes and Joss, 2006). Several studies have pointed out that the removal of some PPCPs in conventional activated sludge (CAS) technologies is often incomplete and in the case of recalcitrant compounds, almost negligible (Carballa et al., 2004; Horii et al., 2007; Suárez et al., 2008). Thus, these substances are emitted back to the environment in WWTP effluents or adsorbed to the sludge, depending on their lipophilic characteristics. When it comes to the environmental assessment of PPCPs by LCA, the lack of characterisation factors (CFs) for the emerging pollutants makes it a difficult task (Alfonsín et al., 2014). In this context, the comprehensive analysis of the facilities must not disregard these emissions despite they are not typically monitored.

The study aims to reveal the benefits of applying this advanced LCI (included GHG and PPCP emissions) versus a more limited approach based on conventional parameters for the environmental assessment of WWTPs. The results of this work focus on providing more accurate emission factors for the aforementioned substances without relying on estimated literature values. Therefore, the outcomes of the study could be of utility to set new benchmark regarding the environmental performance of WWTPs. For this purpose, two WWTPs located in different climatic regions of Spain were selected as case studies. Extensive GHG and PPCP measurement campaigns in the different units of the WWTPs were performed through on-site sampling and included in the LCI.

2. Materials and methods

2.1. Case study selection and description

Two case studies from different climatic regions: Galicia (Northwest Spain) representative for Atlantic climate and Catalonia (Northeast Spain) for Mediterranean one were selected as those prone to present remarkable differences in the impact characterisation results. An exhaustive search on the different WWTP facilities throughout Galicia and Catalonia was fulfilled by means of regional databases with the aim of defining the typical plant sizes (population equivalent, p.e) and the most extensively used configurations. As a result of this analysis, Betanzos WWTP in the case of the Atlantic region and Calafell WWTP in the Mediterranean were found as the most representative facilities and thus singled out as case studies.

Betanzos WWTP was built in 1990 and designed for 25,000 p.e and 6250 m^3/day. The main treatment steps include pre-treatment, secondary treatment and sludge dewatering. The secondary biological treatment consists of two carrousel-shaped biological reactors with suspended biomass, equipped with two horizontal aerators, which include nitrogen removal. Regarding the sludge line, a fraction of the solids settled in the secondary settler is purged to the sludge thickener. Previously to the band filter, the sludge passes through a homogenizer to be mixed with cationic polyelectrolyte and further dewatered in the band filter prior being stored in a silo.

Calafell WWTP was built on 1994 to treat the wastewaters of the municipalities of Calafell and Bellveí and designed for 70,000 population equivalent with a maximum flow of 12,000 m^3/day. After a primary treatment, wastewater is treated in two activated sludge reactors with extended aeration including nitrogen removal, followed by the secondary settler. From these units, the treated wastewater is directly discharged to the submarine sewage. Some differences are observed in the operation of the plant between winter and summer seasons due to fluctuations on the population and changes on the influent composition. A coagulation-flocculation treatment, only operated during summer,