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Review

Life cycle assessment applied to wastewater treatment: State of the art

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ARTICLE INFO

Article history:
Received 27 February 2013
Received in revised form
26 June 2013
Accepted 27 June 2013
Available online xxx

Keywords:
LCA
Review
Literature
Sewage
WWT
State-of-the-art

ABSTRACT

Life cycle assessment (LCA) is a technique to quantify the impacts associated with a product, service or process from cradle-to-grave perspective. Within the field of wastewater treatment (WWT) LCA was first applied in the 1990s. In the pursuit of more environmentally sustainable WWT, it is clear that LCA is a valuable tool to elucidate the broader environmental impacts of design and operation decisions. With growing interest from utilities, practitioners, and researchers in the use of LCA in WWT systems, it is important to make a review of what has been achieved and describe the challenges for the forthcoming years. This work presents a comprehensive review of 45 papers dealing with WWT and LCA. The analysis of the papers showed that within the constraints of the ISO standards, there is variability in the definition of the functional unit and the system boundaries, the selection of the impact assessment methodology and the procedure followed for interpreting the results. The need for stricter adherence to ISO methodological standards to ensure quality and transparency is made clear and emerging challenges for LCA applications in WWT are discussed, including: a paradigm shift from pollutant removal to resource recovery, the adaptation of LCA methodologies to new target

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0043-1354/$ – see front matter
http://dx.doi.org/10.1016/j.watres.2013.06.049

compounds, the development of regional factors, the improvement of the data quality and the reduction of uncertainty. Finally, the need for better integration and communication with decision-makers is highlighted.

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1. Introduction

Life cycle assessment (LCA) is a technique to quantify the impacts associated with all the stages of a product, service or process from cradle-to-grave. LCA had its beginnings in the 1960s and since then a large number of approaches have been developed for different disciplines. In the late 1990s pressure grew to standardize LCA methodologies, which led to the development of LCA standards in the International Standards Organization (ISO) 14000 series. The ISO 14040 and 14044 standards (ISO 14040, 2006; ISO 14044, 2006) define a general methodology but are not designed to define the details for each field in which the method is used. In recent years LCA has gained popularity as an assessment tool for environmental sustainability (Guinée et al., 2011) as evidenced by the rapidly increasing number of publications and databases supporting its implementation.

Within the field of wastewater treatment (WWT), LCA was already applied in the 1990s. Since then, more than forty studies have been published in international peer-reviewed journals using an array of databases, boundary conditions, and impact assessment methods for interpreting the results. In the pursuit of more environmentally sustainable WWT, it is clear that LCA is a valuable tool to elucidate the broader environmental impacts of design and operation decisions (Guest et al., 2009; Larsen et al., 2010). With growing interest from utilities, practitioners, and researchers in the use of LCA in WWT systems, it is important to make a review of what has been achieved and describe the challenges for the forthcoming years.

Several reviews have been published on water treatment and LCA. Friedrich et al. (2007) published a paper that reviewed 20 studies on LCA and wastewater, highlighting key aspects, but did not go deep into the characterization of the studies. A book chapter on Life Cycle Analysis in Wastewater was also published (Ahmed, 2011) where an LCA framework for wastewater treatment was presented. More recently, LCA methodology was included within a review of sustainability assessments of recycled water schemes (Chen et al., 2012). In our opinion, none of these documents provided a complete and comprehensive review on wastewater treatment LCA studies and defined the challenges for the forthcoming years. Therefore, the goal of this paper is to perform a critical review of relevant papers published on the topic and to describe the challenges for LCA applied to WWT. The scope of the review includes only peer-reviewed papers published in journals and one relevant report that is publically available. Papers focused on sludge treatment and disposal without considering the

Please cite this article in press as: Corominas, L., et al., Life cycle assessment applied to wastewater treatment: State of the art, Water Research (2013), http://dx.doi.org/10.1016/j.watres.2013.06.049