WATER RESEARCH 57 (2014) 20–30

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

How environmentally significant is water consumption during wastewater treatment?: Application of recent developments in LCA to WWT technologies used at 3 contrasted geographical locations

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A R T I C L E I N F O

Article history:
Received 25 September 2013
Received in revised form
7 February 2014
Accepted 11 March 2014
Available online 19 March 2014

Keywords:
Life cycle assessment
Wastewater treatment
Water consumption
Water stress index
Freshwater scarcity
River basin scale

A B S T R A C T

Environmental impact assessment models are readily available for the assessment of pollution-related impacts in life cycle assessment (LCA). These models have led to an increased focus on water pollution issues resulting in numerous LCA studies. Recently, there have been significant developments in methods assessing freshwater use. These improvements widen the scope for the assessment of wastewater treatment (WWT) technologies, now allowing us to apprehend, for the first time, a combination of operational (energy and chemicals use), qualitative (environmental pollution) and quantitative (water deprivation) issues in wastewater treatment. This enables us to address the following question: Is water consumption during wastewater treatment environmentally significant compared to other impacts? To answer this question, a standard life cycle inventory (LCI) was performed with a focus on consumptive water uses at plant level, where several WWT technologies were operating, in different climatic conditions. The impacts of water consumption were assessed by integrating regionalized characterization factors for water deprivation within an existing life cycle impact assessment (LCIA) method. Results at the midpoint level, show that water deprivation impacts are highly variable in relation to the chosen WWT technology (water volume used) and of WWTP location (local water scarcity). At the endpoint level, water deprivation impacts on ecosystem quality and on the resource damage categories are significant for WWT technologies with great water uses in water-scarce areas. Therefore, our study shows the consideration of water consumption-related impacts is essential and underlines the need for a greater understanding of the

Abbreviations: AS, activated sludge; IUWM, integrated urban water management; LCA, life cycle assessment; LCIA, life-cycle impact assessment; PE, population-equivalent; vRBF, vertical flow reed bed filters; WC, water consumption; WD, water deprivation; WSI, water stress index; WWT, wastewater treatment; WWTP, wastewater treatment plants.

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http://dx.doi.org/10.1016/j.watres.2014.03.023

water consumption impacts caused by WWT systems. This knowledge will help water managers better mitigate local water deprivation impacts, especially in selecting WWT technologies suitable for arid and semi-arid areas.

1. Introduction

Unconstrained water use has increased worldwide to the point where reliable urban water services can no longer be delivered in many regions. With a large proportion of the world's population currently experiencing water scarcity, urban water services are facing substantial challenges to manage water resources. Integrated urban water management (IUWM) is an emerging approach which considers the entire urban water cycle as an optimizing unit to leverage efficiencies and promote water conservation within the wider river basin. Recently, such initiatives were spearheaded in cities in the developing world by some EU member states within the framework of a World Bank Water Partnership Programme, EU FP6 research project SWITCH (Closas et al., 2013; UNESCO-IHE, 2011). In order to cope with heterogeneous scarcity patterns, we must consider interactions occurring between: climate change and variability, land surface and groundwater hydrology, water engineering and human systems, including societal adaptations (Vörösmarty, 2000).

Since the mid 1990s, the life cycle assessment (LCA) method has proven its worth in the evaluation of the environmental sustainability of water systems by using a whole-system approach over their entire life cycle, and by addressing all relevant types of environmental impacts from global to local. LCA allows for a better assessment of wastewater treatment (WWT) technologies that goes beyond the usual trade-off between treatment efficiencies and quality standards in effluents, e.g. Clean Water Act (US Senate, 1948), European Union Water Framework (European Parliament and Council, 2000), on the one hand, and, energy and chemical expenditures during plant operation and maintenance on the other. LCA is recognised as a standard international tool, ISO 14040 (ISO, 2006a,b).

Recent LCIA methods have been developed to include freshwater use in LCA. The inclusion of such quantitative aspects complements the existing impact assessment models for water quality degradation (namely ecotoxicity, eutrophication and acidification). Methods that quantitatively assess water consider freshwater use as an environmental impact category with potential effects on ecosystem quality (Hanafiah et al., 2011; Milà i Canals et al., 2008; Verones et al., 2012), on human health (Pfister et al., 2009; Bayart et al., 2010; Motoshita et al., 2010; Boulay et al., 2011) and resource use (Bösch et al., 2006; Milà i Canals et al., 2008; Pfister et al., 2009). However, according to a comprehensive review of existing methods addressing freshwater use in LCA (Kounina et al., 2012) no consensus has yet been reached on how best to integrate freshwater use in existing life cycle impact assessment methods. At the LCI level, this review reveals the lack of consistent freshwater balances in most LCA databases and methods.

Recently, 45 papers on LCA of WWTs have been reviewed (Corominas et al., 2013). This review includes the evaluation of environmental performance of conventional activated sludge technologies and non-conventional technologies, as well as whole urban water/wastewater systems, sludge treatment and disposal options. None of these studies propose comprehensive water balances at the WWTP level, nor an assessment of water use-related impacts for these systems. Nevertheless, in the past three years, a small number of studies have addressed freshwater use in extended LCAs of industrial processes (Lévová and Hauschild, 2011) and water supply technologies (Amores et al., 2013; Godskesen et al., 2011; Muñoz et al., 2010).

The novelty of this study lies in the discussion of the first ever combination of qualitative (environmental pollution) and quantitative (water deprivation) issues in wastewater treatment. The most recent research developments in the field of LCA applied to water deprivation are evaluated for (i) their applicability and (ii) their relevance for a practical case study in WWT. This knowledge of consumptive water uses in WWT systems will assist with decision making in choosing the best available/most suitable technologies for a given location/climate by taking into account water use impacts together with other environmental and non-environmental aspects.

Our study assesses consumptive water uses in wastewater treatment plants, which can be related to the amount of water consumed (function of WWT technologies used in the water and sludge lines), and to climatic conditions (such as the specific water availability in a river basin). The goals of this paper are to (i) present baseline LCA results for three WWT technologies; (ii) conduct a detailed water inventory at the plant level; and (iii) test the environmental significance of integrating water consumption related impacts within the baseline LCA results for three distinct geographical locations.

2. Materials and methods

In this section we describe the steps leading to the extended environmental assessment of wastewater treatment technologies, by integrating the impacts on water deprivation. We will follow the recommended scheme of a typical LCA (ISO, 2006a,b): 1. Goal and scope definition, 2. Inventory analysis, 3. Impact assessment, and 4. Interpretation of results.

2.1. *Goal and scope definition*

The overarching goal of this paper is to assess the magnitude of effects caused by water consumption linked to a WWT