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Including the environmental criteria when selecting a wastewater treatment plant☆

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A B S T R A C T

Life Cycle Assessment (LCA) is a methodology to generate environmental impact estimates associated with the life cycle stages of a product or process. The approach facilitates a more comprehensive outlook of the end-of-pipe process impacts, in which wastewater treatment plants (WWTPs) are included. Here we describe the implementation of the LCA methodology within a knowledge-based Decision support system (DSS) in order to include the environmental criteria to the decision making process when selecting the most appropriate process flow diagrams for specific scenarios. A sample group of 22 actual operating facilities in Spain, corresponding to five different typologies were assessed by two relevant impact categories within the system: Eutrophication Potential (EP) and Global Warming Potential (GWP). DSS includes useful tools that support a user in choosing a consistent, near optimum solution for an environmental impact specific problem in a reduced time frame. The synergistic combination of the two methodologies to address the design and assessment of treatment facilities can serve to identify the most sustainable options, embracing simultaneously a wide variety of analysis criteria, and enhancing the calculation of environmental savings. Results of averaged paired-comparison ratios between DSS estimates and facilities operations empirical data showed up to 70% and 95% EP and GWP, respectively. Interestingly, when unbiased operational efficiencies for existing facilities were discarded, the matching ratios increased substantially, up to 99% in both cases. The in-depth analysis of different output data gathered during the conceptual design and simulation of operating facilities using DSS identified the best performing facilities; and was used to improve the environmental performance of WWTPs, even during preliminary design of new facilities. Results demonstrated that combined LCA and DSS implementation is a suitable tool to assess WWTP design during the decision-making process. Following this procedure, a reliable interpretation and discussion of the results can be performed.

1. Introduction

Environmental protection, social and economic development constitutes the three key elements of sustainability (UCN, 2006). In terms of water management, wastewater treatment plants (WWTPs) play a key role as human activity closely associated with sustainability. Society requires that current wastewater treatment successfully fulfill the three aspects of sustainability (Balkema et al., 2002). Currently, WWTPs are typically evaluated by end-of-pipe approaches. The capability of a facility to remove the main contaminant contributors to eutrophication in aquatic bodies and ecosystems has been commended for end-of-pipe approaches as one of the best innovations in environmental protection. In this respect, due to the application of wider sustainability criteria, it is now essential to closely examine WWTP environmental impacts (Davidson et al., 2007).

Life Cycle Assessment (LCA) is a well-established procedure to quantify the environmental impacts associated with a product or process throughout its entire life cycle (also known as life-cycle analysis, ecobalance, and cradle-to-grave analysis) (ISO, 2006a,b). LCA has been implemented to evaluate multiple products and

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processes, (e.g. impacts of different product types, materials, services, or industries with respect to resource use and emissions throughout the supply chain). LCA was applied to wastewater treatment in the 1990s with different objectives (Corominas et al., 2013), such as identifying the main impact contributors within specific processes (see Hospido et al., 2004 or Foley et al., 2010), comparing different technologies and/or facilities (such as Gallego et al., 2008) and assessing the LCA tool methodology and its influence on the evaluation (Renou et al., 2008). Regardless of the particular objectives of the individual studies, the inclusion of a life cycle perspective when assessing WWTP performance includes the consideration of not only the direct impacts associated with the treated effluent discharge (end-of-pipe approach), but also the indirect impacts associated with the inputs (materials and energy use) and outputs (emissions and waste generated) required for the influent treatment (holistic approach). By doing so, a comprehensive representation of the impacts associated with particular treatment processes are provided, and transfer of environmental burdens among compartments (water, air, and soil) or between impact categories (e.g. eutrophication versus climate change) are detected and evaluated. The sooner identification and analyses of environmental impacts are performed, the better our chances of preventing serious future environmental alterations.

Decision support systems (DSSs) enable a user to choose a consistent solution for a particular problem under reduced time frames (Poch et al., 2004). DSSs have gained interest in the wastewater management sector (Hamouda et al., 2009). The approach can be used to justify the multi-criteria decisions of policy-makers (transparency), in lieu of empirical decisions, and provide end-users a tool to explore “what-if” scenarios and examine the response surface to improve the consistency and quality of decisions (Alemany et al., 2005; Comas et al., 2004; McIntosh et al., 2011). DSSs are inherently integrated (e.g. statistical/numerical methods, environmental ontologies), typically consisting of various coupled models, databases, and assessment tools capable of supporting complex decision processes through accessible computer interfaces that present results in a readily understandable form (Huang et al., 2010; Matthies et al., 2007; Shim et al., 2002).

The innovative Novedar decision support system (Novedar DSS[1]) is a tool developed to select between alternative WWTP process layouts, which includes analysis of technical, economic, and social issues and operations (Garrido-Baserba et al., 2011). The software is composed of extensive databases (e.g. legislation, full characterization of WWTP-related technologies, compatibility tables), and methodologies, including Multi-Criteria Analysis (MCA) and Cost-Benefit analysis (CBA). The combined use of these databases, specifically the compatibility knowledge base (C-KB) summarizing the different interactions among the treatment technologies, and the specification knowledge base (S-KB) containing the characteristics (e.g. feasibility, investment cost, removal efficiency) of more than 350 wastewater treatment related technologies results in the synthesis of multiple flow diagrams. Once these flow diagrams are generated, the complementary methodologies operate as a multi-criteria decision approach, and assist in treatment train selection that maximize the objectives defined by the user. Consequently, Novedar DSS facilitates a systematic design of WWTPs, and provides specialized support during the decision-making process via an interface, where users can extract the required information. The range of applications of DSSs in water treatment problems is extensive (Hamouda et al., 2009); issues include selection and design of treatment processes (Benedetti et al., 2008; Comas et al., 2004; Rodriguez-Roda et al., 2000; Vidal et al., 2002) sequencing of selected processes either in parallel or in series in a treatment trains (Joksimovic et al., 2006), and monitoring and control of treatment plants. (Evenson and Baetz, 1994; Hidalgo et al., 2007; Rodriguez-Roda et al., 2002; Turon et al., 2007) or even, for implementing control and operation strategies (Flores-Alsina et al., 2010; Turon et al., 2009; Wotawa et al., 2010). Nevertheless, the development of software such as Novedar_DSS which integrates process synthesis, MCA, CBA and LCA methodologies constitute a pioneer approach and the main highlight of this work, since it clearly overcomes limitations still present in available DSSs.

[1] The development of the Nevada DSS to systematize the design of wastewater treatment plants was performed under the project “Conception of the WWTP of the XXI century”. http://www.novedar.com.

Table 1
Elements selected for WWTP inventory; all data presented in functional unit (FU) (m^3).

Parameter	Unit
Energy use:	
Electricity from the grid	kWh
Chemicals consumption:	
Methanol (CH_3OH)	g
Iron chloride ($FeCl_3$)	g
Polyelectrolyte	g
Other background processes:	
Transport	kg·km
Sludge management	kg ww[c]
Other solids management	kg
Avoided products[a]:	
N as fertilizer	g
P_2O_5 as fertilizer	g
Direct emissions:	
Total nitrogen (Nt) to water[b]	g
Total phosphorous (Pt) to water[b]	g
Chemical Oxygen Demand (COD) to water[b]	g
PO_4^{3-} to water[a]	g
NH_3 to air[a]	g
N_2O to air[a]	g

[a] Associated to the application of sludge to agricultural land.
[b] Associated to the discharge of treated water.
[c] ww = wet weight.

By the joint application of LCA and DSS, this study aims to include the environmental criteria on the decision making process when selecting a possible flow-diagram for a specific wastewater management scenario. So far, the only environmental criterion applied was the accomplishment of the required treated water quality depending on the final discharge or reuse. Going further, this study describes how the implementation of the environmental life cycle thinking took place and presents its application to a set of Spanish WWTPs.

2. Materials and methods

2.1. Decision support system

The Novedar DSS was applied in this study, and has previously been successfully used in feasible WWTP selections (Garrido-Baserba et al., 2011), including economic parameter evaluation (Molinos-Senante et al., 2012). The different databases were developed from a variety of sources, including information from the literature specific to our purposes, and interviews with experts within the Novedar Project. The proposed DSS model was based on a hierarchical decision approach combined with a knowledge-based system, which uses the interaction of different main KBs to provide a required number of optimum alternatives. Garrido-Baserba et al. (2010) reports additional development information regarding Novedar DSS.

2.2. LCA implementation

The LCA methodology is subdivided into four stages (ISO, 2006a): i) define the goals and scope of the study: the definition of the products, processes, or activities, and determine the purposes of the study; ii) conduct a life cycle inventory (LCI) of the waste and resources: quantify the energy use and material sourcing, emissions to atmosphere, water and soil; iii) life cycle impact assessment (LCIA): This phase is aimed at evaluating the significance of potential environmental impacts based on the LCI flow results. LCIA transforms the LCI into impact categories to describe the