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Selecting sewage sludge treatment alternatives in modern wastewater treatment plants using environmental decision support systems

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ABSTRACT

The importance of the sewage sludge treatment within the field of wastewater treatment plants (WWTPs) suggests new dimensions of analysis where the relevance of economic criteria combined with the associated environmental issues are increasing the sludge management complexity. For supporting the decision process and for comparative purposes, this study assesses five alternative configurations for sludge treatment, namely: mesophilic and termophilic anaerobic digestion plus composting, incineration, gasification, and supercritical water oxidation (SCWO). The global warming potential (GWP) and the annual cash flow of each alternative are used to estimate a composite indicator for each alternative. Stakeholders' preferences are integrated into the assessment through the development of five scenarios prioritizing economic or environmental aspects. A case study for a 1 million person equivalent WWTP proved that SCWO is the most adequate option if economic and environmental criteria are considered equally important. However, if the economic assessment is prioritized over the environmental one, thermophilic anaerobic digestion followed by composting turned out to be the most appropriate option. The proposed approach contributes to the implementation of more suitable sewage sludge treatment lines since it provides an indicator for each alternative embracing economic and GWP issues.

1. Introduction

Sewage sludge is inevitably produced in urban wastewater treatment plants (WWTPs), being by far the largest constituent removed. As the number of WWTPs in operation increases, the quantity of sewage sludge generated is also expected to grow very substantially in the future. For instance, in 1992 the European Union produced around 5.5 million metric tons of sludge (dry matter) while in 2010 this figure increased to almost 10 million tons (European Commission, 2010). Moreover, the processing, reuse, and disposal present one of the most complex problems facing engineering in the field of wastewater treatment (Metcalf and Eddy, 2003). The complexity of the sludge treatment management includes offensive substances, mass balances, and variations of the solid characteristics. The selection of the most suitable process involves many possible options which are all linked. The accomplishment of a variety of objectives and multiple criteria increases the complexity of the selection of the most appropriate process to treat sewage sludge. Therefore, this task requires the inclusion of economic and or environmental considerations during the selection or design of current solids-treatment processes flow diagrams.

Some driving factors promoting changes in the design of wastewater treatment process flow diagrams (and subsequently increasing the complexity in the design) are: a) the rising energy

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costs and the need of more electricity and heat to operate the plants; b) sustainability and environmental concerns, such as global warming and greenhouse gases (GHG) emissions; c) regulation as factor stimulating the development of new technologies (Olsson, 2013).

Along with technical factors, economic and environmental aspects must be considered in sludge treatment. The sludge management costs impact plays a central role in any type of WWTP analysis, since the solids handling and processing accounts for as much as 30%–50% of wastewater treatment facility's costs (Neyens et al., 2004; GWRC, 2008). However, it should be emphasized that sludge contains 10 times the energy required to treat it. Therefore, new emergent perspectives lead to consider this waste as a product to be used beneficially after treatment (WEF, 1998). It has been proven to be technically feasible to recover energy from the sludge, which can be directly used in wastewater treatment or be sold to the network, reducing the facility's dependency on conventional electricity and helping the stressed public budgets. In other words, from an economic point of view, energy recovery means incomes as direct benefit or avoided cost.

Concerns about sustainability involve not just the consideration of technical and economic aspects during the decision-making process but also environmental issues. In this context, technologies for treating sludge are considered as solutions not exempt of impacts. The life cycle perspective and the carbon footprint analysis entails the consideration of direct impacts associated to the sludge treatment, combined with indirect impacts associated to the inputs (materials and energy use) and outputs (emissions and wastes generated). The most widely accepted and well-established procedure to quantify the environmental impacts regarding a product or process throughout its whole life cycle is the Life Cycle Assessment (LCA) (Cooney, 2009; ISO, 2006). Sludge treatment is not exempt from this trend and a wide number of works were carried out aimed to assess the environmental impacts of the sludge line in WWTPs (Hospido et al., 2005; Righi et al., 2013; Cao and Pawlowski, 2013). Although eutrophication, ozone depletion, photochemical ozone creation, depletion of abiotic resources and human toxicity are impact categories usually evaluated through LCA, it is well known that global warming potential (GWP) is not one of the most common impact categories in this methodology. Nevertheless, since WWTPs are big consumers of electric power, the GWP has been commonly applied in order to both quantify indirect emissions and include political and social concerns about this impact (Larsen, 2007; Rodriguez et al., 2011).

As environmental and economic concerns increases, the interest shifts from just building technically suitable sludge-treatment options to also consider environmentally friendly and economically feasible ones (Bertanza et al., 2014). The growing number of treatment technologies which can be potentially implemented for the very same case provides water managers with a variety of alternatives. A high number of combinations of sludge-treatment flow diagrams incorporating unit operations and processes can be proposed (Metcalf and Eddy, 2003). In this respect, the Environmental Decision Support Systems (EDSS) are assessment tools capable of supporting complex decision making processes. EDSS integrate coupled models, databases, numerical methods, environmental ontologies, etc. (He et al., 2006; Matthies et al., 2007; Shim et al., 2002; Huang, 2010). EDSS assist decision makers in choosing between alternative solutions or actions by applying knowledge about the decision domain to reach recommendations for the various options (Fox and Das, 2000; Poch et al., 2004).

Previous experiences successfully applied Decision Support System (DSS) tools for the selection of the best alternatives in the wastewater treatment domain. Alemany et al. (2005) used an EDSS to identify adequate small wastewater treatment technologies or low populated communities, although only technical aspects were considered. Molinos-Senante et al. (2012) also used an EDSS for the selection of SWWT, incorporating the economic vector in the selection analysis. Dinesh (2003) was assisted by a DSS for the evaluation and selection of treatment alternatives for reclamation and reuse applications. Joksimovic (2008) used a DSS for considering alternative options for reuse treatment and also network distribution aspects. Nevertheless, none of those approaches quantified or considered the potential environmental impacts of the selected alternatives. In this respect, the works from Hamouda (2011) and Garrido-Baserba (2013) integrate sustainability indicators (i.e. LCA) during the decision-making of the selection of the most appropriate treatment alternative. However, works that include the development and application of EDSS for supporting decisions regarding sewage sludge treatment technologies are much more limited, with only a few cases focusing in the selection of the best decision management option for composting or sludge application on agricultural soils (Horn et al., 2003; Passuello et al., 2008).

In this work, the NovEDAR_EDSS software was used for the identification and assessment of the most appropriate sludge treatment technologies for the design of WWTPs. The NovEDAR_EDSS was conceived as an integrated software employing artificial intelligence techniques combined with different analytical tools: Multicriteria Decision Analysis (MCDA) methodologies (Flores-Alsina and Rodríguez-Roda, 2008), LCA (Lundin, 2000), Cost-Benefit Analysis (CBA) and Environmental-Benefit Analysis (EBA) (Molinos-Senante et al., 2011). The NovEDAR_EDSS has previously been successfully used in feasible WWTP selections (Garrido-Baserba et al., 2011; Garrido-Baserba et al., 2012), 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 EDSS model was based on a hierarchical decision approach combined with a knowledge-based system, which uses the interaction of different main knowledge bases to provide a required number of optimum alternatives. Garrido-Baserba et al. (2010) reported additional development information regarding NovEDAR_EDSS. This software integrates not only water line information but also an exhaustive database about sewage sludge treatment technologies. It is to be highlighted that the NovEDAR_EDSS includes information about investment and operating costs, as well as direct and indirect GHG emissions of traditional and novel sludge treatment technologies. Hence, it is a useful tool for identifying strategies for sludge treatment based on the stakeholders' perspective (economic, technical or environmental criteria).

The aim of this study is to assess the selection between five alternatives (see Table 3 in Section 2.1) for sludge treatment, embracing economic and GWP issues. In doing so, five scenarios regarding the stakeholders' preferences (see Table 5 in Section 3.3) are evaluated using a WWTP with a one million person equivalent

Table 1
Case study parameters required for the sludge treatment selection.

Input data		Case study
Scenario characteristics	Peq	1,000,000
	Flow rate (m^3/d)	200,000
Influent characteristics (mg/L)	Total SS	450
	BOD	400
	COD	800
Biosolids	SRT (days)	10

(Peq: person equivalent; COD: Chemical Oxygen Demand; BOD: Biological Oxygen Demand; SRT: Solid Retention Time).