Science of the Total Environment 497–498 (2014) 607–617

Contents lists available at ScienceDirect

Science of the Total Environment

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

Assessing the sustainability of small wastewater treatment systems: A composite indicator approach

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HIGHLIGHTS

- Sustainability assessment of WWTPs involving economic, environmental and social dimension.
- Development of a composite indicator for seven wastewater treatment technologies for small communities.
- Application of the analytical hierarchical process (AHP) to assign weights to each indicator.
- A scenario analysis illustrates that constructed wetlands technology is the most sustainable in five out of the seven scenarios evaluated.

ARTICLE INFO

Article history:
Received 8 April 2014
Received in revised form 31 July 2014
Accepted 8 August 2014
Available online 27 August 2014

Editor: Simon Pollard

Keywords:
Composite indicator
Sustainability
Small communities
Wastewater treatment
Decision making
Analytical hierarchical process (AHP)

ABSTRACT

The assessment of the sustainability of wastewater treatment (WWT) systems has gained interest in recent years. However, most previous studies have focused on environmental and/or economic dimensions ignoring social aspects. Moreover, they tend to be based on sets of indicators rather than providing a holistic assessment. To overcome this limitation, this paper proposes an innovative methodology to assess the sustainability of WWT systems based on the development of a composite indicator embracing economic, environmental and social issues. Subsequently, the global sustainability of seven WWT technologies for secondary treatment in small communities is compared. The joint application of the analytical hierarchical process (AHP) to assign weights to each indicator allows the incorporation of the preferences of experts. Initially, the global sustainability of the WWT technologies evaluated is quite similar. However, a scenario analysis illustrates that constructed wetlands technology is the most sustainable in five out of the seven scenarios evaluated. Moreover, extended aeration and rotating biological contactors are identified as the technologies with the lowest variability in their sustainability. Hence, in an uncertain context, they might be considered the preferred options. The proposed approach contributes to ease of interpretation of a complex problem such as the selection of the most sustainable WWT alternative.

1. Introduction

Lack of wastewater treatment (WWT) can be a source of pollution, a hazard for the health of human populations and the environment alike. Hence, in the last few decades significant efforts have been made worldwide to implement or improve sanitation systems and wastewater treatment plants (WWTPs). However, in 2010, 2500 million people were still without access to improved sanitation (UNICEF and WHO, 2012). Therefore, the construction and operation of WWT facilities is a challenge that cannot be neglected by authorities. Although in developed regions almost all the wastewater generated (95%) is collected and treated, in the near future, additional WWTPs should be built or updated. For example, to achieve good ecological status as stated by European Directive 2000/60/EC (Water Framework Directive), appropriate treatment of wastewater in small agglomerations should be implemented (Molinos-Senante et al., 2011). However, the legislation on urban WWT (Directive 91/271/EEC) does not state any duty in relation to agglomerations of less than 2000 people equivalent (p.e.).

The implementation of WWTPs requires investment, but the selection of the most appropriate WWT technology is not only an economic issue as other criteria such as environmental and social aspects must be taken into account in the decision process (Popovic et al., 2013). There is clearly a need for a paradigm shift in WWT, considering environmental

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http://dx.doi.org/10.1016/j.scitotenv.2014.08.026

and social aspects in the decision-making-process, not just technical and economic issues (Møller et al., 2012). In this context, the selection of the most appropriate plant design involves the accomplishment of a variety of objectives and the consideration of multiple criteria; therefore, it is a complex problem (Flores-Alsina et al., 2010).

Since the 1990s, there has been an increasing emphasis on defining and measuring the sustainability of service systems (Lundin et al., 1999). The WWT industry is not excluded from this trend and there is widespread recognition of the need to implement more sustainable WWT technologies the performance of which are balanced by environmental, economic and societal sustainability (Muga and Mihelcic, 2008).

The assessment of the sustainability of different WWT technologies would provide very useful information to support the decision-making process (Høibye et al., 2008), but a major limitation is the lack of consensus on the definition of sustainability in general and in particular in the framework of WWT (Hoffmann et al., 2000). In other words, the incorporation of sustainability aspects in the decision-making process is challenging because the definition of sustainable development only sketches a concept rather than giving a rigid rule that can be applied right away (Balkema et al., 2002). Although sustainability can and will be interpreted differently by different people, what it is clear is that it involves three dimensions namely, economic, environmental and social (WCED, 1987).

Despite the limited methods available at present that are widely accepted in measuring sustainability (Lozano-Oyola et al., 2012), several studies have aimed to assess the sustainability of WWT systems following two main approaches: (i) the development of a single indicator integrating different criteria; (ii) the development of a set of multidisciplinary indicators. For instance, the outcome of exergy analysis, economic analysis, or life cycle assessment (LCA) is a single indicator. As noted by Corominas et al. (2013), during the last decade the use of LCA as a tool to assess the environmental performance of WWTPs has been widespread. Moreover, some studies have refined the standard LCA methodology to focus the assessment on some environmental effects (Wang et al., 2012). Nevertheless, it should be noted that LCA is limited to the evaluation of the environmental sustainability of products and/or processes. Hence, additional indicators introducing economic and social dimensions are needed to measure the sustainability of WWT technologies. Regarding economic analysis in the framework of WWT systems, cost-benefit analysis (CBA) is one of the tools most commonly applied to support the decision-making process (Fan et al., in press; Guest et al., 2009). Although market and non-market costs and benefits can theoretically be included in economic assessment, in practice, due to the complexity of valuing environmental externalities, very few studies introduce them in the evaluation of the economics of WWT technologies (Hardisty et al., 2013; Molinos-Senante et al., 2013). Even in such exceptions, the social dimension is not incorporated in the assessment of sustainability despite the fact that it is known that social aspects play an important role in the implementation of technology (Balkema et al., 2002).

The second approach used to assess the sustainability of WWT technologies is based on the development of a battery of indicators embracing economic, environmental and social issues. Following this approach, several lists of sustainability indicators have been proposed. Most studies have focused on evaluating one WWT process rather than comparing different WWT technologies. Moreover, as in the first approach, the majority of studies do not address social issues; therefore, they do not fully capture the concept of sustainability (Lundin et al., 1999; Balkema et al., 2002; Dixon et al., 2003; Tsagarakis et al., 2003; Møller et al., 2012; Popovic et al., 2013). Despite being a minority, there are some studies which have compared the sustainability of WWT processes. In this context, Muga and Mihelcic (2008) were pioneering in comparing seven WWT technologies grouped into three categories, namely mechanical, lagoon and land treatment systems. In doing so, a set of indicators that incorporate economical, environmental and societal issues was developed and estimated. Høibye et al. (2008) compared five advanced WWT technologies. However, their assessment included technical, economical and environmental aspects, but did not consider societal sustainability. More recently, Estrada et al. (2011) compared seven odor treatment technologies in WWTPs based upon the triple-bottom-line, which includes the assessment of environmental performance, social responsibility and process economics. These three studies – Muga and Mihelcic (2008), Høibye et al. (2008) and Estrada et al. (2011) – proposed and applied an indicator system made up of a considerable number of elements, making them difficult to use by decision makers in some cases (Lozano-Oyola et al., 2012).

A major limitation of assessing sustainability based on a set of indicators is that it does not provide a holistic assessment. Using this approach, the value of each indicator relates separately to each sustainability issue. Hence, the outcome of the evaluation process is not a measure of global sustainability, which indicates the overall state of all the factors integrated in the assessment (Blancas et al., 2010). To overcome this limitation, the initial indicators should be aggregated, converting the indicator system into a composite indicator which provides a multidimensional assessment of sustainability. This index is obtained as a mathematical combination of the indicators that represent the different components of the subject under analysis (Merz et al., 2013). Although there are many alternative methodologies for obtaining composite indicators (OECD, 2008), all of them assume that the subjectivity involved in developing the indicator is part of the process. Despite criticism of composite indicators on the basis of this subjectivity, they have been used widely as tools in the decision-making process (Blancas et al., 2011). Moreover, in the framework of sustainability assessment, composite indicators are simple and suitable tools for carrying out comparative analysis. Hence, they have been used to assess the sustainability of a wide range of activities, services and processes, such as tourism destinations (Blancas et al., 2011; Pérez et al., 2013), farming practices (Roy et al., 2014), solid waste management systems (Menikpura et al., 2012) and manufacturing industries (Voces et al., 2012), among others. However, to the best of our knowledge, there is no theoretical development nor empirical application that uses composite indicators to assess and/or compare the sustainability of WWT technologies.

Taking into account that composite indicators are useful tools for aiding public policy decisions and the dissemination of information to the general public (Lozano-Oyola et al., 2012), the objectives of this paper are twofold. The first is to propose a set of indicators to assess the sustainability of WWT technologies, embracing economic, environmental and social issues. Subsequently – and for the first time in the framework of the assessment of WWT technologies – the system of indicators is aggregated into a composite indicator, providing a global measure of sustainability. The second objective is to assess and compare the sustainability of seven different technologies established for secondary treatment in small WWTPs. Two of the seven technologies evaluated are extensive, whereas the others are intensive technologies. Hence, our study also provides some insights into the differences between both types of technology in relation to sustainability.

The outcome of the assessment developed in this study is a composite indicator for each WWT technology evaluated. Hence, this study contributes to facilitating access by stakeholders and decision makers to an interpretation of a complex and multidimensional decision problem, such as the selection of the most sustainable technologies from a wide set of possibilities.

2. Materials and methods

2.1. Indicator system for assessing the sustainability of wastewater treatment technologies

The definition of sustainability indicators is an important step as the selection of sustainable options is based on these indicators (Balkema et al., 2002). Various lists of sustainability indicators can be found in