Journal of Cleaner Production xxx (2016) 1–13

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Economic and environmental analysis of five Chinese rural toilet technologies based on the economic input–output life cycle assessment

Hui Gao [a, b], Chuanbin Zhou [a, *], Feng Li [a], Baolong Han [a], Xiuxia Li [c]

[a] State Key Laboratory of Urban and Region Ecology, Research Center for Eco-Environmental Science, Chinese Academy of Sciences, Beijing 100085, China
[b] College of Urban and Environmental Science, Xinyang Normal University, Xinyang 46400, Henan, China
[c] School of Art and Design, Xinxiang University, Xinxiang 453000, Henan, China

A R T I C L E I N F O

Article history:
Received 8 April 2015
Received in revised form
20 November 2015
Accepted 25 December 2015
Available online xxx

Keywords:
Economic input–output life cycle assessment model
Net present value
Rainwater harvesting
Urine diverting composting toilet

A B S T R A C T

Building toilets are critical infrastructure to promote public health. The current sanitation technology in developed countries is based on diluting human excreta with large volumes of centrally provided potable water. This approach is a poor use of water resources and is also inefficient and energy intensive, which is not suitable for water-shortage rural areas of northern China. Therefore, comprehensive schemes of Chinese rural toilets, including standard flushing, rainwater harvesting flushing systems, urine separation and composting systems, were considered in this study by means of five scenarios simulation. Economic net present value method was adopted for economic analysis and economic input–output life cycle assessment model based on Chinese economic input–output table and life cycle database was developed for comparing energy consumption and greenhouse gas emission implications, aiming to guide the selection of toilet schemes. A mountainous village in Mentougou District of Beijing was taken as the example. Based on total cost and net present value method, the results showed that scenario 5, namely urine diverting composting systems, outweighed the other four alternatives on the cost even in the different discount rates ranging from 0% to 10%; scenario 3, namely urine-diversion and potable water flushing toilet, was sub-optimal economic solution which net present value was negative when discount rate was over 8%. This study also present scenario 3's environmental superiority to scenario 5 on energy consumption and greenhouse gas emission. These two technologies were proved viable options for standard flushing toilet. Nevertheless, for another two scenarios of rainwater harvesting flushing toilets, they had higher amounts of investment, energy consumption and greenhouse gas emission due to the high investment on rainwater tank construction. Moreover, the vast majority of construction materials required high energy consumption and were carbon intensive sectors in China. Finally, some suggestions were given for the implementation of urine separation toilets and composting toilets in the practical application. Meanwhile, impact of the rising water price in selecting alternative technologies and tradeoff about the priority consideration for rural toilet technologies were analyzed in this study. Considering the great significance of rainwater harvesting toilet technology to save the water resources, measures of how much government should subsidize for guarantee its extension and motivation was discussed as well.

1. Introduction

Facing a rapidly growing world population, the pressure on natural resources is continuously increasing, both on the local and global level. Simultaneously, a large number of people in developing countries, particularly in rural areas, have to be supplied with reliable systems for safe drinking water and sanitation to prevent the spread of infectious diseases and to overcome poverty.

The design of standard sanitation technologies in developed countries is based on the premise that excreta are waste and that waste is only suitable for disposal (Esrey et al., 2001). This “waste” is collected centrally in sewer pipes using centrally provided potable

* Corresponding author. Tel./fax: +86 10 62943807.
E-mail address: cbzhou@rcees.ac.cn (C. Zhou).

http://dx.doi.org/10.1016/j.jclepro.2015.12.089
0959-6526/

quality water as the transport medium. This approach is low efficient, energy intensive and also is a waste of water resource. Many drinking water systems lose as much as 20% of their treated potable quality water due to leaks in their pipe networks (Mehta, 2009). According to the Ministry of Housing and Urban–Rural Development (MOHURD), the electricity consumption of municipal wastewater treatment plant was 10 billion kilowatt-hours in 2013, accounting for 0.2% of China's total electricity use. And 10 billion Chinese Yuan (CNY) will be saved if power consumption is reduced by 10% (MOHURD, 2014).

Unlike traditional sanitation systems, the concept of ecological sanitation (EcoSan) relies on an environmentally and ecologically sound management of water, nutrient and energy fluxes (Otterpohl, 2002). Decentralized sanitation systems with source control of pollutants and reduced water consumption are, however, implemented throughout Europe, and certain aspects of their environmental benefits, economic viability and social acceptability have been investigated for different scales of implementation and wastewater loads (Dallas et al., 2004; Langergraber and Muellegger, 2005; Benetto et al., 2009). Rural areas in developing countries need especially to build decentralized sanitation infrastructure due to dispersed people and limited funds. Sanitation toilet such as rainwater-flushed-toilets, waterless urinals toilets and composting toilets not only reduce or eliminate the use of potable water but also improve rural health condition. From the views of system design, alternative selection and effect simulation, it was reported and discussed focusing on Ecosan (Henriques and Louis, 2011; Magid et al., 2006; Katukiza et al., 2012; Montangero and Belevi, 2008).

Ecosan and alternative sanitation concepts are widely ignored by public planning authorities, architects and engineers in China. In most rural areas of China, wastewater is typically conveyed in combined sewers that also convey storm water. According to the statistics of MOHURD, 96 percent of villages do not have drainage pipelines and sewage treatment systems. Centralized sewage treatment systems in Chinese vast rural areas are not appropriate. In addition, more than 450 million rural inhabitants continue to endure insufficient water supplies, rainwater harvesting will help to increase the self-sufficiency of rural areas in terms of water demand. China began to introduce some projects for ecological sanitation in the late 1990s, and domestic research is being in the initiative stage. As far as these achievements were concerned, they focused mainly on program design and optimization (Wang and Zhou, 2008; Zhou et al., 2008, 2010).

The practices of the Chinese ecological sanitation systems focus on rural areas and emphasize drinking water improvement, toilet amelioration, and excreta disposal, for example, urine diverting without flushing ecological toilet systems and excreta fermentation biogas systems.

Since the early 1970s, research on biogas production has been developed rapidly in China. Combined with regional situation, eco-agricultural models has emerged taking biogas as a core, including 'Three in One" pattern combing the biogas digester with a pigpen and toilet in southern China, "Four in One" pattern combing the biogas digester, pigpen, solar greenhouse, and toilet in northern China, and "Five in One" pattern combing the biogas digester with solar-powered barns, water-saving irrigation system, water cellar, and toilet in northwest China. In addition, focusing on the effect evaluation of biogas-linked system, previous research (Chen et al., 2012; Chen and Chen, 2013a,b; Chen and Chen, 2014) made contributions on the study of energy shortage and global warming with the means of life cycle assessment and emergy analysis. However, household biogas use in rural China encounters constraints in straw fermentation, cold fermentation technology and management (Chen et al., 2010). Ecological toilet technology provides a new mentality for excreta treatment and water conservation under the current countryside situation. According to relevant data from the 2012 Chinese Rural Statistical Yearbook, the sanitary cover rate in rural areas is 71.7%. In United Nations Millennium Development Goals (UNMDGs), the Chinese government promises that the cover rate is able to reach 75% in 2015 years; therefore, China needs to increase efforts toward rural sanitation toilet construction.

Because centralized water and wastewater treatment systems are the norm, the life cycle impact of water treatment and supply (Stokes and Horvath, 2009; Vince et al., 2008; Friedrich et al., 2009) and wastewater treatment systems (Gallego et al., 2008; Zhang and Wilson, 2000) have been extensively studied. Nevertheless, there is only limited information available on the comparative life cycle impact of technologies that reduce potable water use in rural toilets. Some previous studies suggest that composting toilets and the use of rainwater to flush toilets may, in some cases, have a lower environmental impact compared to standard systems (Remy and Jekel, 2008; Chiu et al., 2009; Crettaz et al., 1999). How to select a appropriate and more sustainable technologies for rural area is urgent, however, at present, analysis and comparison of rainwater technology, composting toilet technology, and urine diverting fixtures technology have not been previously studied.

In previous studies, economic input output models was verified its advantage on obviating conventional life cycle on boundary assumptions, this model represented all the supplier relationships in the supply chain for industrial production. Therefore, some researches about economic and environmental analysis of industrial sector(Egilmez et al., 2013; Hsieh and Kung, 2013) and specific product (Jiang et al., 2014a; Nanaki and Koroneos, 2013; Jiang et al., 2014b; Wang et al., 2014; Wang and Yuan, 2014) appeared with Economic Input Output Life Cycle Assessment (EIO-LCA) as a tool. Application of this method was shown to be feasible. Nevertheless, owning to the different economic development levels, it had much different on the results of environment assessment, so the widespread use of Carnegie Mellon EIO-LCA software could not be completely followed by other countries and regions. In this study, we firstly attempted to build a model based on Chinese Economic Input–Output Table and Life Cycle Database, contributing to analysis and compare five alternative schemes with helping to select feasible rural toilet technology.

This study was supported by a demonstration pilot project on ecological settlement transformation, which integrated ecological engineering, including ecological toilets, organic waste reclamation management and sewage treatment. This project aimed to improve the ecological environment and promote the ecological quality of the Chinese northern rural area. As a part of the project research results, a mountainous village named Shuiyuzui in the Mentougou District in Beijing was selected as a case study. Environmentally friendly, affordable and simple operation eco-toilet technology was explored and applied to reduce none-point pollution from the source. Water shortages and dispersed population are problems in this area, as in other Chinese northern rural regions. Planning and building eco-toilet should be based on local natural conditions, and then water-saving and decentralized eco-sanitation technologies need to be prioritized. Alternative sanitation technologies, such as rainwater-flushing-toilets, urine-diversion toilets and composting toilets, can reduce or eliminate the use of potable water to flush toilets. These alternative technologies can have good technical performance (Ghisi, 2006; Gajurel et al., 2003), and if they have comparatively lower costs and environmental impact, they will replace the current potable water based sanitation systems in the future.

The goal of this study was to investigate the cost, energy consumption and global warming implications of the use of standard and alternative sanitation technologies in a mountain village. The