Renewable and Sustainable Energy Reviews 49 (2015) 169–177

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Life cycle assessment of food waste-based biogas generation

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A R T I C L E I N F O

Article history:
Received 5 December 2014
Accepted 26 April 2015

Keywords:
Life-cycle assessment
Food waste
Energy recovery
Anaerobic digestion
Biogas

A B S T R A C T

Life cycle assessment was performed by using the ReCiPe model to estimate the environmental effects of three food waste (FW)-based biogas generation scenarios. Uncertainty analysis was also conducted to confirm and add credibility to the study. Results showed that the potential impacts of human toxicity, freshwater eutrophication, marine ecotoxicity, and fossil depletion had dominant contributions to the overall environmental impact. Electricity consumption during anaerobic digestion (AD) and the transportation of raw materials during landfill stage exhibited high potential impacts. The FW to landfill scenario with and without energy recovery had the highest environmental impact. Moreover, uncertainty analysis indicated that landfill was unsuitable for treating FW. Increasing biogas generation capacity, improving electricity generation efficiency, optimizing the energy structure of China, and decreasing electricity consumption during the AD stage are effective ways for reducing the adverse effects on the environment.

Contents

1. Introduction

Significant amounts of food waste (FW) have dramatically increased worldwide because of the vast increase in population and urbanization. FW includes a large proportion of the total

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http://dx.doi.org/10.1016/j.rser.2015.04.164
1364-0321/

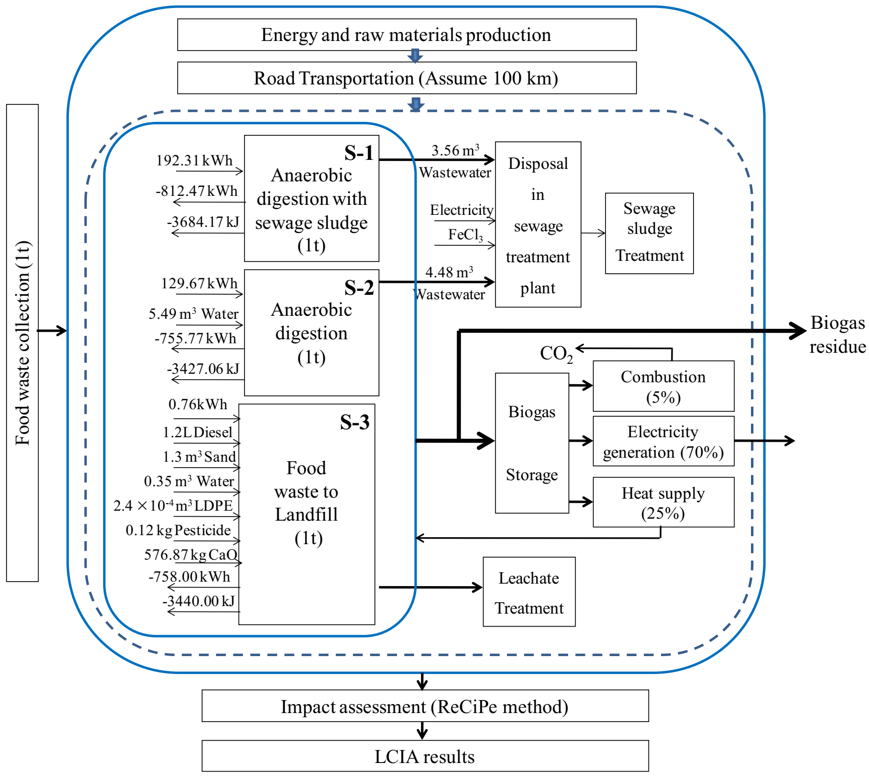

Fig. 1. System boundary.

municipal solid waste (MSW) of the country. For instance, the quantity of FW in the United States, United Kingdom, France, Germany, Holland, Switzerland, Japan, Korea, and Singapore accounted for approximately 12%, 27%, 22%, 15%, 21%, 20%, 23%, 23%, and 30% of the total solid waste, respectively [1]. In China, the amount of FW reached 9×10^7 t in 2010 (i.e., approximately 38% of the total solid waste) with a 10% increase each year [2]. FW contains numerous nutrient elements and has great energy recovery potential. It also contains large amounts of pathogenic organisms that are harmful to humans and the environment. If handled improperly, aggravated environmental problems will threat ecosystem human health. Therefore, a comprehensive method for evaluating environmental burdens is highly needed.

Life-cycle assessment (LCA) is used to evaluate the environmental impacts associated with the entire life-cycle treatment of a product, process, or activity [3]. LCA has been widely used for eco-labeling programs, strategic planning, and marketing. LCA applications also include product design, process improvement, and consumer education. The environmental impact of FW treatment has been studied extensively by using the LCA method [4–6]. However, no studies on FW treatment in China have been published in English-language peer-reviewed journals. In addition, most previous studies only focused on several impact categories (e.g., climate change and acidification). Moreover, although the quantification of uncertainties in the LCA related to input and output results are important for correct interpretation and use, researchers have been conducting LCA studies of FW treatment without taking uncertainty into consideration. Furthermore, China is well known as one of the largest energy consumers and greenhouse gas emitters in the world [7]. With increasing environmental and energy pressure, China has focused on using renewable energy to reduce environmental effects. Biogas generated from different types of biomasses (e.g., straw, sugar beet, maize, grass silage, sewage sludge, and FW) has great potential to regenerate electricity. However, most of the biogas (88%) produced from landfill or AD stages are emitted to the air without being utilized [8].

Accordingly, research needs to address certain issues to present a systematic and reliable assessment. The following should be conducted: (a) all impact categories must be considered; (b) uncertainty analysis should be conducted to provide a credible assessment; (c) energy recovery from biogas generated from landfill and AD stages should be taken into consideration; (d) biogas production capacity on commonly used FW treatment technologies (i.e., landfill and AD) in China should be compared to different biomasses in the world; (e) the key factors for reducing the potential environmental burden generated by FW treatment should be identified. A LCA was conducted to evaluate the environmental impact of three FW treatment scenarios in China.

2. Scope definition

2.1. Functional unit

The functional unit is the base for the treatment comparison in the life-cycle inventory (LCI). In this study, the management of 1t volatile solid (VS) is selected. All emissions, transport, materials, wastewater treatment, energy consumption and recovery levels are based on this functional unit.

2.2. System boundary

Three scenarios for FW treatment are considered in this study. These scenarios include (a) the AD of FW and sludge (S-1), (b) AD of FW (S-2), and (c) FW to landfill (S-3). Fig. 1 shows the system boundary and flow of main materials of each scenario. For all scenarios, the common processes are biogas utilization, direct air emissions (i.e., carbon dioxide, nitrogen, hydrogen, sulfur dioxide, nitrogen oxides, and hydrogen sulfide), raw materials production