Renewable and Sustainable Energy Reviews 79 (2017) 204–221

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

A review of global strategies promoting the conversion of food waste to bioenergy via anaerobic digestion

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ARTICLE INFO

Keywords:
Food waste
Biogas
Anaerobic digestion
Policy
Subsidies

ABSTRACT

The objective of this paper is to review policies around the world that promote the conversion of food waste to biogas. We review policies and operational projects from a diverse set of case study countries including South Korea, China, France, Germany, and the United Kingdom. Using a four-step analysis methodology that focuses on each country's (1) food waste background, (2) food-waste-to-biogas policy environment, (3) status quo of food waste-to-biogas projects and (4) future policy/project-level challenges, we provide a comprehensive cross-country review of food waste-to-biogas policy developments. We find that, while each surveyed country has unique strengths and weaknesses in their policy structure, Asian and European countries also do face similar bottlenecks in the food waste-to-biogas sector. Some specific findings include: (1) highly centralized policies in Asian case countries such as China and South Korea have led to the rapid build-up of a food waste-to-biogas sector; (2) European case countries such as France and the United Kingdom have succeeded in implementing policies that incentivize the production of multiple outputs within treatment facilities; (3) South Korea is a good example of how countries can implement smart waste management systems to decrease the volume of FW generated at the source; (4) South Korea, Germany and France have successfully built many co-digestion projects treating FW together with other waste sources, indicating that project operators in countries have understood the multiple benefits of co-digestion. The geographic breadth of the case studies, and the best practices and challenges identified for each country, should prove highly useful for policy-makers in developing countries who are seeking to enhance food waste management via anaerobic treatment methods.

1. Introduction

Countries around the world waste enormous amounts of food, and good strategies are needed to convert this waste into useful resources. An estimated 1.6 gigatonnes of food waste is produced annually, accounting for 27% of the 6 gigatonnes of total agricultural production for both food/non-food uses [22]. Food waste, which is the dominant part of the organic fraction of municipal solid waste (OFMSW), is putrescible. This means that when buried in a landfill, food waste decomposes to form methane, a greenhouse gas with a global warming potential 25 times greater than CO_2 on a 100-year time scale [70] Effective management and treatment of OFMSW is an increasingly prominent issue for countries around the world, especially in developing countries, where FW accounts for the dominant fraction of municipal solid waste (MSW). In Bangladesh for instance, organic waste constitutes about 75% of MSW, and in China on average it constituted about 52.6% in 2010, compared to just 25% in the USA or 32% in France [94].

Both developed countries and developing countries are struggling to deal with these massive amounts of food waste, and as a result, different regions around the world have devised frameworks for the appropriate management of this waste. For instance, the European Union's Waste Framework Directive 2008/98/EC devised a waste management hierarchy that recommended – in order of preference – prevention, preparation for re-use, recycling, other recovery (i.e. energy recovery) and landfill treatment [20]. Some specific EU countries have even more stringent standards; in Belgium for instance, the Public Flemish Waste Management Company proposed the following food waste management hierarchy: prevention; use for human nutrition; conversion for human nutrition; use for animal feed; use as raw

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http://dx.doi.org/10.1016/j.rser.2017.05.047
Received 24 March 2016; Received in revised form 12 March 2017; Accepted 11 May 2017

material in industry; process into fertilizer by anaerobic digestion or composting; use as renewable energy; incineration; and landfill [86]. Germany, a country that is relatively advanced in the realm of waste management, still faces problems such as the over-capacity of waste treatment plants, miscommunication between municipalities and private waste management companies, financing the collection and recycling of biowaste, and continued reliance on incarnation. As a result, the country is actively devising strategies to increase circular economy principles regarding waste management [63].

In the developing world, countries are also building frameworks to deal with food waste. In the Chinese context for instance, food waste source reduction, centralized recycling, and waste-to-resource recycling are the development trends of food waste management. Since 2011, China has launched food waste treatment pilot projects in 100 cities across five stages [91]. These projects include collection, transportation, treatment and utilization of food waste. They also propose integrated solutions for waste oil/fat, solid waste, and liquid waste, in order to achieve an optimal waste recycling scenario and safe disposal.

While there has been good progress in some developing regions such as China regarding food waste management, many other countries have completely inadequate foundations for enhanced food waste management. In Nigeria for instance, there exist few policies regarding food waste management and recycling. Only 8% of food waste (FW) is recycled for compost, and recycling operations are generally dealt with by the informal sector [77]. In Ghana in 2010, about 90% of the total 4.5 million tons of generated municipal solid waste (MSW) was ineffectively dumped through landfill, placing a burden on human health, despite the fact that 68% of the annual MSW generated in Ghana is organic matter – mostly food waste [15]. Brazil and Mexico have poor FW recycling systems due to inadequate legislative frameworks, low participation by the private sector and limited funding to enhance FW diversion activities [31]. Jamaica lacks centralized food waste recycling. India has high levels of FW, but it is mostly disposed of in dump sites rather than recycled [78].

In this context, there is a strong need to provide policymakers in developing countries with an update of global strategies that deal with food waste. This article thus reviews policies that promote the conversion of food waste to bioenergy, with a focus on anaerobic digestion (AD), a mature technology for biogas production. In addition, we examine the status of some AD biogas projects around the world, which will be useful to benchmark the output performance of projects in developing countries.

This research is especially timely given that there is increased awareness on behalf of policymakers around the world regarding the principles of circular economy (CE). CE represents a sustainable alternative to the current linear system, primarily by recirculating material resources for new product development [69]. Initiatives based on principles are increasingly becoming more important in international/regional plans for creating sustainable futures [30]. George et al. [24] showed that, contrary to the Environmental Kuznets Curve, environmental quality cannot be maintained via linear economic growth, but only by an increase in the environmental self-renewal rate or the recycling ratio.

Given that enhanced FW management fits within the desired objectives of CE principles, this review should be highly useful for project developers and policy makers in developing countries. In Asia, China and South Korea were selected as case study countries. In Europe, Germany, France and the United Kingdom were examined. In the Americas, Brazil and the United States were analyzed. These countries were chosen due to (1) their ambitious and varied policy mechanisms (or lack of good policies, chosen to provide cautionary tales of bad management) to enhance food waste treatment and (2) their varied geographic and economic conditions. The geographic scope should prove useful for policymakers who seek solutions that are applicable to their domestic situation.

This research is also especially significant because there are no examples in recent literature providing a comprehensive update on the status quo of policies regarding biogas production from food waste in Asia and Europe. Moreover, recent studies give a misleading picture of the status quo in countries such as China regarding FW treatment projects. For instance, Thi et al. [78] have claimed that “only seven FW treatment sites are currently operating in China”, based on a 2011 source. This is no longer the case in China. Moreover, there are no in-depth comparative treatments of Chinese or European policies.

Other literature has only focused on more technical aspects of food waste treatment. For example, Dung et al. [19] focused on the bioenergy potential of FW in 21 different countries by applying five different methods of bioenergy production. Xu et al. [92] focused on life-cycle assessment of food waste-based biogas generation using the ReCiPe model, and found that AD treatment was the preferable treatment option compared to two other scenario. Iacovidou et al. [34] discussed policy intervention for household FW disposal (FWD) units in the UK, finding that FWDs should be either regulated and banned completely. Halloran et al. [32] highlighted the importance of multi-stakeholder collaboration in solving food waste challenges, taking Denmark as a case study. Zhang et al. [99] examined the combined effect of crude fat content and initial substrate concentration on batch anaerobic digestion characteristics of food waste. Brancoli et al. [100] conducted a life-cycle assessment of supermarket food waste, concluding that bread waste contributes largely to a supermarket's environmental footprint. Fisgativa et al. [101] conducted an extensive physiochemical characterization of FW and found that correlations between FW characteristics may help to predict the performance of anaerobic digestion. Magyar et al. [102] explored the conversion of sugar-rich food waste to energy; they demonstrated how food waste could be efficiently converted to ethanol and used for making biodiesel. Zhang et al. [103] evaluated the enhancement of biogas production in anaerobic co-digestion of food waste and waste activated sludge by biological co-pretreatment. De Clercq et al. [104] performed an in-depth economic performance evaluation of bio-waste treatment technology at the facility level, using a case study in southern China. De Clercq et al. [105] conducted a performance evaluation of restaurant food waste and biowaste to biogas pilot projects in China and suggested implications for national policy.

The growing body of technical-oriented research about food waste indicates wide interest in this important field. However, to the authors’ knowledge, there has been no review of policies regarding anaerobic digestion of food waste specifically. This paper thus represents a vital addition to the literature.

The remainder of the article is structured as follows. Sections 2–8 delve provide deep analysis of food waste-to-biogas developments in each case country via a four-step analysis that focuses on each country's (1) food waste background, (2) food-waste-to-biogas policy environment, (3) status quo of food waste-to-biogas projects and (4) future policy/project-level challenges. This 4-step methodology was based on the author's judgement of a logical structure, as previous studies on this topic have not yet been conducted. Moreover, this four-step structure should prove accessible to the multiple governmental, institutional and private sector stakeholders involved in food waste management. Section 9 discusses best practices/challenges derived from the analysis and associated policy implications for developing countries. Conclusions are provided in Section 10.

2. China

2.1. Food waste background

In the Chinese context, “food waste” collectively refers to restaurant waste, household kitchen waste and discarded expired food. China produces a lot of food waste, but most of it ends up in landfills. In 2013, 172 million tons of MSW were collected in China, and 55.86% of this