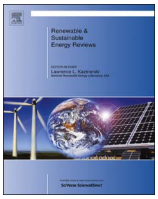
Renewable and Sustainable Energy Reviews 72 (2017) 354–362

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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



Full scale co-digestion of wastewater sludge and food waste: Bottlenecks and possibilities

Long D. Nghiem[a,b,*], Konrad Koch[b], David Bolzonella[c], Jörg E. Drewes[b]

[a] Strategic Water Infrastructure Laboratory, School of Civil, Mining and Environmental Engineering, University of Wollongong, NSW 2522, Australia
[b] Chair of Urban Water Systems Engineering, Technical University of Munich, Am Coulombwall 3, 85748 Garching, Germany
[c] Department of Biotechnology, University of Verona, Strada Le Grazie, 15 I-37134 Verona, Italy

ARTICLE INFO

Keywords:
Anaerobic co-digestion
Wastewater sludge
Food waste
Energy recovery
Full-scale implementation

ABSTRACT

Wastewater treatment plants in many countries use anaerobic digesters for biosolids management and biogas generation. Opportunities exist to utilise the spare capacity of these digesters to co-digest food waste and sludge for energy recovery and a range of other economic and environmental benefits. This paper provides a critical perspective for full-scale implementation of co-digestion of food waste and wastewater sludge. Data compiled from full-scale facilities and the peer-reviewed literature revealed several key bottlenecks hindering full-scale implementation of co-digestion. Indeed, co-digestion applications remain concentrated mostly in countries or regions with favourable energy and waste management policies. Not all environmental benefits from waste diversion and resource recovery can be readily monetarised into revenue to support co-digestion projects. Our field surveys also revealed the important issue of inert impurities in food waste with significant implication to the planning, design, and operation of food waste processing and co-digestion plants. Other pertinent issues include regulatory uncertainty regarding gate fee, the lack of viable options for biogas utilisation, food waste collection and processing, impacts of co-digestion on biosolids reuse and downstream biogas utilisation, and lack of design and operation experience. Effort to address these bottlenecks and promote co-digestion requires a multi-disciplinary approach.

1. Introduction

Energy security, resource depletion, and pollution prevention are three of the most vexing challenges of our time. They often manifest themselves in the form of climate change, economic crisis, and geopolitical instability [1,2]. These challenges call for a fundamental paradigm shift in resource and environmental management, which has resulted in the emergence of the circular economy concept. In a circular economy, products at the end of their service life or waste materials are turned into resources for another purpose, thus closing loops in industrial ecosystems and minimizing waste [3]. It is estimated that by shifting to a circular economy, several European countries can potentially reduce their national greenhouse-gas emissions by 70%, grow their workforce by 4%, and decrease their dependency from resource and energy import [4].

The transformation toward a circular economy can be already seen in the wastewater servicing sector. Traditionally, wastewater treatment plants (WWTPs) have been designed with the end-of-pipe treatment philosophy of meeting discharge standards to receiving water bodies while waste produced during treatment is destined for landfill or incineration. Conventional WWTPs typically include activated sludge treatment of wastewater and anaerobic digestion of the produced sludge. Most WWTPs adopting anaerobic digestion for sludge treatment face similar problems namely low organic loading and biogas (methane) yields due to the low biodegradability of wastewater sludge. In addition, WWTPs are often designed with spare capacity to cater for variation in the wastewater flow and future population growth [5]. Recent progress in water conservation and slow or even declining population growth in many developed countries have left many wastewater treatment facilities with spare digester capacity that is not and will not be utilised in the future.

Wastewater treatment is vital for environmental protection, but it is also an energy intensive activity. The treatment of municipal wastewater accounts for about 3% of global electricity consumption and 5% of global greenhouse gas emission [2,6]. Thus, it is not surprising that the wastewater industry has actively explored options to move toward energy-neutral operation.

A typical energy demand for biological wastewater treatment is in the range of 20–30 kWh per person equivalent per year [7]. On the other hand, given the current engineering limitations, energy recovery

---

* Corresponding author at: Strategic Water Infrastructure Laboratory, School of Civil, Mining and Environmental Engineering, University of Wollongong, NSW 2522, Australia.
E-mail address: longn@uow.edu.au (L.D. Nghiem).

http://dx.doi.org/10.1016/j.rser.2017.01.062
Received 24 July 2016; Received in revised form 9 November 2016; Accepted 9 January 2017
1364-0321/

via anaerobic digestion of wastewater sludge is only about 15–18 kWh per person equivalent per year. In other words, under an optimal condition, WWTPs can potentially achieve up to about 65% energy self-sufficiency by fully utilising their sludge for energy recovery [7,8]. In practice, a typical WWTP can currently offset 20–30% of the energy consumption and greenhouse gas emission [7,9]. Thus, a viable and pragmatic approach is to co-digest municipal organic wastes in combination with municipal wastewater sludge using the spare digestion capacity at WWTPs to increase biogas production [10–12]. This approach does not only allow WWTPs to be energy-neutral but also reduce the cost of municipal organic waste management [13] while facilitating nutrient recycling [14,15].

Waste disposal options by landfilling or incineration are expensive and not compatible with the concept of a circular economy. Ongoing leachate management and extensive monitoring for potential groundwater and air pollution are required during active landfill operation and even up to 50 years post-closure [16]. On the other hand, extensive air pollution control is required for the waste incineration. Incineration of waste materials also results in significant greenhouse gas emission. In addition, both landfilling and incineration options offer very limited possibilities for resource recovery. Contrary to the traditional end-of-pipe treatment philosophy, in a circular economy, waste materials in general and the organic wastes in particular are a rich vein of resources in terms of energy and nutrient waiting to be tapped.

The opportunity to utilise spare capacity at WWTPs for municipal organic waste co-digestion is immense. Nevertheless, co-digestion at WWTPs also faces many significant hurdles that must be resolved through the dissemination of full-scale operation experience in both waste separation and biogas technology. Indeed, despite the rapid increase in the number of co-digestion studies at laboratory scale in the literature over the last couple of years [17], the number of pilot- and full-scale studies (particularly those dealing with operational issues) is still very limited. Of a particular note, waste materials can be highly variable in composition and data from laboratory-scale experiments using a small sample are not readily transferable to full-scale operation.

It is noteworthy that the bulk of organic waste from municipal origin is essentially food waste or food related waste, thus, the term food waste can be broadly used to refer to municipal organic waste. In this study, food waste materials include both avoidable (such as food scraps, unsaleable produces from supermarket, unusable beverage, and waste milk) and unavoidable streams (such as food processing waste, coffee ground, tea leaves, dairy processing waste, and fat oil and grease (FOG)).

Based on visits of full-scale facilities and collaboration between authors and plant operators, this paper discusses the current state of wastewater sludge and food waste co-digestion. Operation and design experience at four co-digestion plants using wastewater sludge and food waste in Italy and Germany are described in detail to reveal potential lessons for future projects. Key bottlenecks in the integration of co-digestion to WWTPs are identified and delineated. This paper provides useful background information for the formulation of a systematic roadmap for future development of co-digestion using experiences from existing resource recovery facilities promoting the concept of a circular economy.

2. Key drivers of co-digestion

Anaerobic co-digestion of food waste and wastewater sludge provides a range of economic and environmental benefits (Fig. 1). These include the diversion of putrescible waste from landfills and the ability to recover essential resources in a circular economy. Both of these are key environmental and social drivers of co-digestion. There are also financial benefits in the form of gate fee and revenue through renewable energy production. While financial consideration is essential to justify the commercial viability of a co-digestion project, only a portion of the environmental benefits from waste diversion and resource recovery can be monetarised. In fact, the economic benefit of co-digestion is often seen as a side effect and some full scale co-digestion projects have to rely at least partially on government subsidies [18,19].

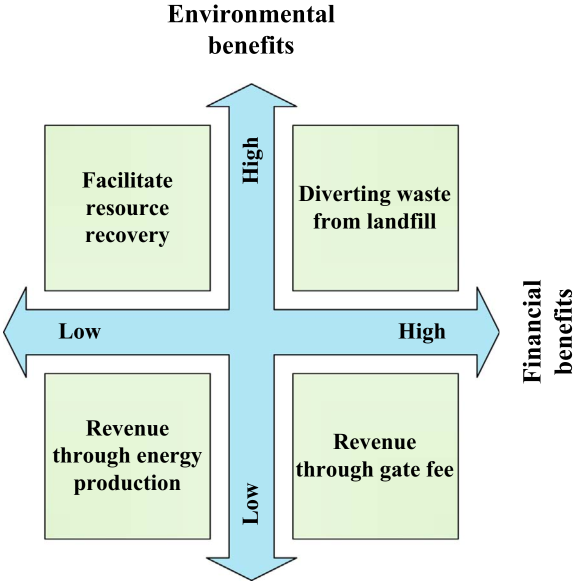


Fig. 1. Key drivers for co-digestion.

Environmental benefits of diverting food waste from conventional disposal methods such as landfilling and incineration are significant. The high water content (typically 80–90% of the total weight [20]) of food waste renders incineration an energy intensive and costly option. Food waste accounts for 25–60% of municipal solid waste (MSW) [21,22]. Thus, by removing food waste from MSW, landfilling space can be saved for inert waste materials with significantly less environmental impact during landfilling operation and post-closure maintenance. Food waste is readily biodegradable. As a result, after deposition in landfills, food waste is the most significant contributor to methane gas production. According to Eriksson et al. [23], each kg of food waste can ultimately generate up to 0.1 m^3 of methane gas. About 15% of this methane gas is captured for beneficial use or flaring [23]. Thus, fugitive greenhouse gas emission from landfilling of food waste could amount to 3.1 gigatonnes CO_2-eq/year based on the global figure of 1.6 gigatonnes of food waste each year [24]. Co-digestion, on the other hand, allows for complete capturing and beneficial utilisation of methane gas from food waste. In addition, the contents of chemical oxygen demand (COD) and ammonia (NH_3-N) in landfill leachate are directly linked to the fraction of putrescible organic carbon (which is essentially food waste) in MSW [22]. During anaerobic co-digestion, the COD is transferred into energy-rich methane while nitrogen is converted into ammonium in the aqueous phase and can be effectively removed in the WWTP by conventional nitrification/denitrification processes or energy-saving nitrogen removal processes such as deammonification. Hence, the removal of food waste from landfilling materials can lessen the risk of environmental damage due to leakage of leachate into groundwater and the cost of leachate management.

Food waste can be a resource with great potential for energy production and nutrient recovery. Energy production from food waste is an attractive proposition and the subject of numerous recent reviews (see for examples [21,25–29]).

In addition, food waste contains important nutrients for crops including phosphorus and nitrogen. Anaerobic co-digestion provides an excellent platform for nutrient recycling either through nutrients extraction from the sludge centrate (also known as reject water) and/or biosolids reuse via land applications as a fertilizer. Several commercial systems have recently been developed to recover nutrients from sludge