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Mini review

Electricity generation comparison of food waste-based bioenergy with wind and solar powers: A mini review

Ngoc Bao Dung Thi [a,*], Chiu-Yue Lin [b,c], Gopalakrishnan Kumar [d]

[a] Faculty of Environment and Labour Safety, Ton Duc Thang University, Ho Chi Minh City 700000, Viet Nam
[b] Green Energy Technologies, Ton Duc Thang University, Ho Chi Minh City 700000, Viet Nam
[c] Green Energy Development Center, Feng Chia University, Taichung 40724, Taiwan
[d] Center for Materials Cycles and Waste Management Research, National Institute for Environmental Studies, Tsukuba 305-0053, Japan

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ABSTRACT

The food waste treatment-based anaerobic digestion has been proven to play a primary role in electricity industry with high potentially economic benefits, which could reduce electricity prices in comparison with other renewable energy resources such as wind and solar power. The levelized costs of electricity were reported to be 65, 190, 130 and 204 US$ MWh^{-1} for food waste treatment in anaerobic landfill, anaerobic digestion biogas, solar power, and wind power, respectively. As examples, the approaches of food waste treatment via anaerobic digestion to provide a partial energy supply for many countries in future were estimated as 42.9 TWh yr^{-1} in China (sharing 0.87% of total electricity generation), 7.04 TWh yr^{-1} in Japan (0.64% of total electricity generation) and 13.3 TWh yr^{-1} in the US (0.31% of total electricity generation). Electricity generation by treating food waste is promised to play an important role in renewable energy management. Comparing with wind and solar powers, converting food waste to bioenergy provides the lowest investment costs (500 US$ kW^{-1}) and low operation cost (0.1 US$ kWh^{-1}). With some limits in geography and season of other renewable powers, using food waste for electricity generation is supposedly to be a suitable solution for balancing energy demand in many countries.

1. Introduction

In recent years, the escalating increase in energy consumption due to rapid industrial development has threatened the environmental balance. The generation of organic wastes, especially, food waste (FW) also results in environmental pollution problems if not well managed. The FW contains many biodegradable organic components and could be anaerobically digested to produce biogas as a green bioenergy [1]. Moreover, the approach of the FW as a source of bioenergy feedstock is expected to solve some issues of waste treatment and green energy generation and also overcome the controversy on using crops for fuel/energy.

Treating FW via anaerobic processes could greatly maximize the efficiency of hydrogen and methane production for potential energy use [2]. This energy conversion might offer a stable electricity source for many countries. Some previous studies have demonstrated that FW could also be treated by a two-step of dark- and photo-fermentation for bio-hydrogen production or three-stage fermentation for bio-hydrogen and bio-methane [3]. At present, anaerobic digestion (AD) is the most commercial method for FW treatment and biogas recovery (mostly bio-methane generation). AD could give the highest energy benefits, and is the most suitable method for the commercialization of FW treatment, in which the electricity generation of one-phase and two-phase anaerobic digestion is about 220 and 404 kWh t^{-1} FW, respectively [1].

AD is considered as a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. The process involves three phases of conversion including hydrolysis, acidogenesis, and methanogenesis. Four main groups of bacteria involved each phase include i) Hydrolytic bacteria, ii) Acetogenic bacteria, iii) Acetoclastic methanogens, and iv) Hydrogenotrophic methanogens. The two-phase process for methane is usually a sequential process (more complex than methane production, one-phase) [4]. AD process mostly generates methane content up to 75% of total biogas [5]. For one- or two-

* Corresponding author.
E-mail address: thingocbaodung@tdt.edu.vn (N.B.D. Thi).

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Nomenclature

AD	anaerobic digestion
FW	food waste
kWh	kilowatt-hour
LCOE	Levelized cost of electricity
MWh	megawatt-hour
REN21	renewable energy policy network for the 21st century
SP	solar power
TWh	tegawatt-hour
US$	United States Dollar
WP	wind power

phase process for methane production composing of methanogenic bacteria, together with halophilic and thermo-acidophilic bacteria, makes up a group of micro-organisms called Archaebacteria. The methane content in a single process step can be up to 85–90% prior to the gas cleaning step.

At batch scale, the one-phase system with organic loading rate about 24 m^3 t^{-1} FW and pH control at 7 could produce a stable methane yield at about 364 ± 7 mL CH_4 g^{-1} VS [6]. There are some other studies of AD process for hydrogen and methane productions as below:

– Two-phase thermophilic AD process: operation temperature is at 55 °C with pH control at 5.2 ± 0.2 (First phase) and 8.1 ± 0.1 (Second phase). Biogas yield is about 690 L kg^{-1} total volatile solids $(TVS)_{added}$ (7% H_2, 58% CH_4 and 35% CO_2) [7].
– Dark fermentation coupled with AD process: operation temperature is at 55 °C with pH control at 5.7 ± 0.3 (First phase) and 8.4 ± 0.2 (Second phase). The hydrogen yield is up to 66.7 L kg^{-1} TVS_{added} and CH_4 yield 720 L kg^{-1} TVS_{added} (CH_4 58%, H_2 6.9%, CO_2 36%) [8].
– The two-phase hydrogen/methane fermenting reactor has controlled temperature around 33 ± 4 °C, pH 5.3 ± 0.2 (First phase) and 36 ± 4, pH 7.4 ± 0.3 (Second phase). Total biogas is up to 2446 Nm^3 d^{-1} (with H_2 yield around 1223 Nm^3 d^{-1}) [9].

The system of one-phase fermentation for methane has been developed at full scale plant, which was reported to generate about 383 kWh t^{-1} of FW [10]. While it is revealed that two-phase process for hydrogen and methane produces a total electricity of 780 kWh t^{-1} of FW [11,12].

Treating FW to produce biogas and then to generate electricity exposes that FW is becoming a prospective electricity supplement source among various renewable energy suppliers. However, the competition of this electricity with other main renewable energy sources of wind and solar is not reported in any studies or researches. Therefore, this mini-review aims to obtain a comparison between FW-based bioenergy via one-phase and two-phase AD in commercial scale plants with wind power (WP) and solar power (SW) in terms of economic and energy benefit evaluations.

2. Overview of food waste to bioenergy via anaerobic digestion

AD is a popular method for treating organic wastes [13]. There are formulae developed by Gary and Jenkins as a technical guideline of AD process for FW that has been adopted by many FW to biogas via AD studies [14]. Theoretically, one tonne of FW could potentially produce 247 m^3 methane and generate approximately 90 GJ of heat or 847 kWh electricity [15]. This review used these values to compute the maximum energy potential of treating FW-based theoretical AD process.

FW treatment-based AD technology has been widely practiced around the world. There are 1455 AD facilities in the US and 124 AD plants in Europe [16]. At present, the largest capacity is at Cedar Grove in Everett in the US at 280,000 t FW yr^{-1} [17]. For larger scales, such as commercial FW treatment facilities in Canada and the US, energy output of FW treatment-based AD technology was found to be as high as 220 kWh t^{-1} FW [16]. This review uses this energy output value to compute energy potential from FW treatment via one-phase AD process, the results are presented in Table 1.

The results of pilot-scale plant operating with two continuous stirred tank reactors (0.2 m^3 for first phase [dark-fermentation for hydrogen) and 0.76 m^3 for second phase (AD for methane)] showed that hydrogen production was about 66.7 L kg^{-1} TVS_{added} with the final biogas amount 0.72 m^3 kg^{-1} TVS_{added} [8]. It illustrates that dark-fermentation coupling with AD enhances biogas yield. The maximum electricity generation in the entire process was about 404 kWh t^{-1} FW [8]. This value is used to compute the energy potential of FW treatment via two-phase AD process. In fact, in a comparison between one-phase with two-phase of AD, the potential electricity of two-phase AD could have been expected to exhibit higher energy yield than that of one-phase AD system [18].

There are thousands of large-scale FW treatment plants in France, Italy, Germany, Denmark, UK, Sweden, US, Canada and Southeast Asian countries [4,17]. For power generation purposes, many organic waste-AD plants are connected to the current grid of nationwide energy supplies in Germany, Switzerland, Netherlands, UK and Sweden [4,17]. As of now, German AD based FW treatment AD has reached 2 Mt of FW per year, which accounts for 16.3% of their annual FW generation. The Netherlands have disposed their FW by about 0.8 Mt yr^{-1} with the average capacity per AD facility being 54 kt yr^{-1} [4,17]. The UK has reached 500 kt of FW treatment by AD (3% of total FW) for an average capacity of 35 kt FW yr^{-1} per plant.

Table 1 presents the energy benefits in comparison with WP and SP in Australia, US, Germany, China and Japan. China has the highest population and also contributes the highest amount of FW in the world [1]. It is estimated that China with 195 Mt of FW generation annually could mean producing approximately 42.9 TWh yr^{-1} of electricity via one-phase AD process (sharing 0.76% total electricity generation) and 78.8 TWh yr^{-1} of electricity via two-phase AD process (sharing 1.39% total electricity generation) [12]. This could be an impressive share in the total renewable power generation of China in comparison with WP and SP generation. Meanwhile, the US is the world leader of bio-power generation, but they use biomass from forest such as fast-growing trees, crop residues (wheat straw, barley straw, and sugarcane wastes) and animal dung, while the FW is not commonly used in commercial energy production [19]. It is estimated that the FW of the US could produce about 13.4 TWh yr^{-1} (sharing 0.31% total electricity generation) via one-phase AD and 24.6 TWh yr^{-1} (sharing 0.57% total electricity generation) via two-phase AD processes, respectively [12].

Among the European countries, Germany has the highest chance of expanding AD technology to treat FW since they could convert 2.7 TWh yr^{-1} (sharing 0.44% of total national electricity generation) via one-phase AD process and 4.96 TWh yr^{-1} (sharing 0.81% total electricity generation) via two-phase AD process. It could highlight the steadily increasing role in biological treatment for FW in Europe, whereas Germany targets using natural gas, which has been set to reach 6% of total gas consumption by 2020, and 10% by 2030 [20].