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Food waste conversion options in Singapore: Environmental impacts based on an LCA perspective

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A R T I C L E I N F O

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A B S T R A C T

Proper management and recycling of huge volumes of food waste is one of the challenges faced by Singapore. Semakau island — the only offshore landfill of the nation — only accepts inert, inorganic solid waste and therefore a large bulk of food waste is directed to incinerators. A remaining small percent is sent for recycling via anaerobic digestion (AD), followed by composting of the digestate material. This article investigates the environmental performance of four food waste conversion scenarios — based on a life cycle assessment perspective — taking into account air emissions, useful energy from the incinerators and AD process, as well as carbon dioxide mitigation from the compost products derived from the digestate material and a proposed aerobic composting system. The life cycle impact results were generated for global warming, acidification, eutrophication, photochemical oxidation and energy use. The total normalized results showed that a small-scale proposed aerobic composting system is more environmentally favorable than incinerators, but less ideal compared to the AD process. By making full use of the AD's Recycling Phase II process alone, the Singapore Green Plan's 2012 aim to increase the recycling of food waste to 30% can easily be achieved, along with reduced global warming impacts.

1. Introduction

Municipal solid waste (MSW) volumes from modern societies have increased over the years, out of which, a considerable fraction of the solid waste stream is food scraps. The annual generation of food waste in Singapore was 542,700 tons in 2006 and reached about 570,000 tons in the year 2008 (NEA, 2009). Proper treatment and management of food waste is a challenge faced by any developing nation as untreated and unmanaged food waste creates odor, hygiene concerns and cause adverse environmental impacts.

Singapore is a highly populated, industrialized city with limited land area that can be used as landfills. Semakau Landfill is Singapore's only landfill for waste disposal. Singapore's offshore landfill may only accept inert wastes that are inorganic. Therefore, no food waste is sent to the landfill and the majority of food waste is directed to incinerators (Tan and Khoo, 2006). A remaining 10–15% is sent for recycling via anaerobic digestion (AD), followed by composting of the digestate material.

According to the Singapore Green Plan 2012, up to 30% of food waste recycling has to be achieved year 2012 (MEWR, 2008). This article will focus on the present and future options of increasing food waste recycling, which includes a proposed aerobic composting plant. The environmental impacts of the food waste conversion options are projected based on a life cycle assessment perspective.

2. Food waste conversion options

Since Singapore has become a signatory to the Kyoto Protocol in April 2006, energy efficient and more sustainable waste treatment methods will be sought after. The food conversion methods that are introduced in this article are: incineration, recycling via AD combined with composting of digestate matter, and a proposed aerobic composting plant.

2.1. Incineration (waste-to-energy)

Incineration or waste-to-energy has been employed widely to generate energy from waste materials, as well as to reduce the volume of waste substantially. As land is limited, Singapore has adopted the policy of incinerating all 'incinerable' solid waste, including food waste (NEA, 2009). Incineration is a mature technology that involves the combustion and conversion of MSW into heat and energy (McDougall and Hruska, 2000). Incinerators are able to reduce the volume of solid wastes by 80%, which makes them popular in countries that have limited territory for landfills. Singapore's four incinerators are Ulu Pandan, Tuas, Senoko and Tuas South. The proportions of food waste input treated by the four incinerators are calculated to be 12.88%, 16.52%, 34.66% and 35.95% respectively. A typical incinerator requires the energy input of 70 kWh/ton waste and generates around 20% ash (Tan and Khoo, 2006).

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2.2. Anaerobic digestion and composting

The recycling of food waste is carried out by a Singapore-based company IUT Global Pte. Ltd. (IUT Global, 2006) using anaerobic digestion (AD) method combined with composting. The main product, bio-gas, from the AD process is transferred into gas engines to generate energy, which is then sold to the national grid. An additional step in the process converts the residues from the anaerobic digester, or digestate material, into bio-compost. Fig. 1 describes the process of the AD and the composting of digestate.

The composting process involves the use of microorganisms to break down the residues in the presence of oxygen, thus avoiding the production of methane. The bio-compost material can be used as a replacement of mineral fertilizers. From the compost products, carbon dioxide savings can be achieved by the avoided production of the mineral fertilizers (Schleiss et al., 2008). The nutrient contents of the bio-compost are assumed to be 0.0076 kg N and 0.0011 kg P per kg for digested matter by AD process (Finnveden et al., 2000).

The waste food recycling process by IUT Global is separated into two phases, each with similar AD processes but different capacities. The present Phase I recycling has an installed capacity of 3.5 MW power and treats 300 tons of food waste per day. From here, the digestate material is sent to composting plant I to produce bio-compost. Phase II has an installed capacity of 6 MW power and treats 500 tons of food waste per day; digestate from Phase II is sent to composting plant II (CDM, Clean Development Mechanism, 2006). The combined capacities of phases I and II can achieve the goal of 800 tpd (tons per day) food waste recycling for the whole of Singapore. In this analysis, we assume that the present Phase I recycling plant is able to run at full capacity, and Phase II will be also be operating at full capacity in the near future.

The recycling of food waste into electrical energy and compost is IUT Global's solution to reduce the amount of food waste entering incineration plants, and at the same time earn carbon credits from reduced greenhouse gas emissions (CDM, Clean Development Mechanism, 2006).

2.3. Proposed small-scale composting facility

An additional composting plant is proposed for the purpose of increasing the recycling options, and also for diverting food waste away from incinerators. The proposed composting process is an aerobic type based on Lee et al. (2007). As shown in Fig. 2, the only output of the composting plant is bio-compost. It is assumed that sawdust material does not impose any additional environmental impacts for the system and is not included in the investigation.

The bio-compost from aerobic composting can also be used to replace mineral fertilizer. Both AD bio-compost (from digestate matter) and aerobic bio-compost products are expected to contain different nutrients. The P and N content of compost product reported by Finnveden et al. (2000) will be assumed in this case, which is 0.0083 kg N and 0.002 kg P per kg per bio-compost.

Table 1 summarizes the energy requirements of each process, and the amounts of the main products — electrical energy and bio-compost.

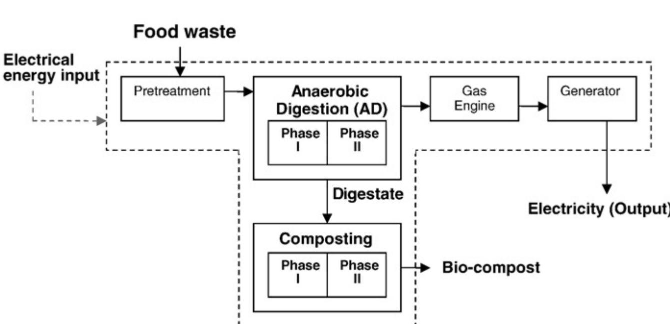

Fig. 1. Food waste recycling facility — adapted from IUT Global (2006).

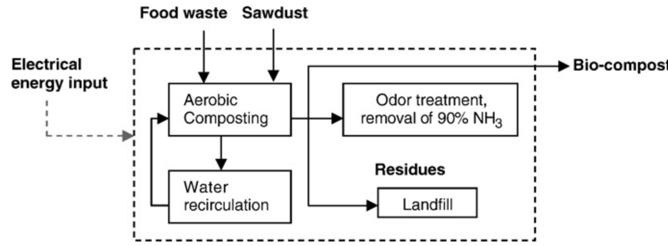

Fig. 2. Aerobic composting food waste — adapted from Lee et al. (2007).

The information was supplied by IUT Global's Clean Development Mechanism report document (CDM, Clean Development Mechanism, 2006) and Lee et al. (2007).

Greenhouse gas savings in terms of CO_2-eq are reported to be 5.3 kg/kg N mineral fertilizer and 0.52 kg/kg P mineral fertilizer (Schleiss et al., 2008).

3. Life cycle assessment

The evaluation of the environmental impacts of waste treatment or conversion options is extremely important for the purpose of protecting the community at large as well as preserving the natural environmental settings of a small island-nation. Life cycle assessment or LCA is seen as an emerging tool to measure and compare the environmental impacts of human activities (Rebitzer et al., 2004; Pennington et al., 2004). LCA models have become the principal decision support tools for policy makers at all levels for waste management strategies (Christensen et al., 2007). One of the benefits of LCA is the identification and quantification of the potential environmental impacts of different waste management technologies (Buttol et al., 2007). In another example, the environmental performances of various solid waste treatment systems were evaluated by Khoo (2009) to support a holistic approach to sustainable waste management and to provide direction for developing environmentally sound strategies.

3.1. Goal and scope

The goal of the LCA is to provide information to governmental-level organizations on technology selection for future food waste conversion in Singapore. The following waste conversion scenarios are modeled to compare their environmental impacts:

Scenario 1: Recycling of food waste (Phase I and Composting I), with the rest incinerated

Scenario 2: Recycling of food waste (Phase II and Composting II), with the rest incinerated

Table 1
Information of waste treatment options.

Food waste treatment	Pretreatment (kWh/ton)	Energy consumption (kWh/ton)	Energy output (kWh/ton)	Amount of compost (tons/year)
Recycling by anaerobic digester (AD) and composting by IUT Global (2006)				
Phase I recycling and Composting I	25.0	32.0	260.82	66,000
Phase II recycling and Composting II		24.0	268.27	112,200
Incinerators (waste-to-energy)				
Ulu Pandan	0	70.0	89.0	0
Tuas	0		128.0	0
Senoko	0		136.0	0
Tuas South	0		174.0	0
Proposed aerobic composting plant (Lee et al., 2007)				
Proposed composting plant	62.0		0	25,534.68