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Comparison between the technologies for food waste treatment

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Abstract

Based on life cycle assessment (LCA), this paper compares five different methods for food waste treatment. To achieve it, the environmental performance of food waste in Shandong University as a case study is evaluated. The case study indicates that saving food is the ultimate way to reduce environment impact and the distance for transportation also affects a lot. The result of comparison shows that landfill contributes most to climate change, which is about 10 times larger than others. For acidification and eutrophication, incineration shows the worst result 7.77 PAF*m^2yr. And composting has the largest impact on carcinogens with the result 3.49E-05 DALY. On the whole, the waste treatment technologies are recommended in proper sequence from anaerobic digestion, heat-moisture reaction, composting and incineration to landfill.

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Keywords: Food Waste; LCA; Anaerobic digestion; Disposal

1. Introduction

According to Gustavsson et al. [1], 1.3 billion tons of food is wasted worldwide every year, representing one third of the global yearly food production. In China, the volume of food waste reached 245,000 tons a day in 2014, accounting for about 50% of municipal solid waste [2-3]. However, food waste can be valuable resource when it is managed reasonably and effectively, meanwhile reducing the impacts on the environment [4-5]. Large volumes of food waste mainly come from office canteens, university canteens and the food service industry. Among all the sources, it is interesting to look at

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university canteens since college students may have higher environmental awareness than ordinary people and tend to be easier to manage their behavior [6].

There have been many studies on treatment of municipal solid waste. Food waste, as a special category of municipal solid waste, has the feature of high moisture, salinity, organic and oil content, which requires different methods of treatment from common municipal solid waste [7]. Common treatment methods for handling food waste include anaerobic digestion, landfill, incineration, composting and heat-moisture reaction [8]. Anaerobic fermentation produces methane as the main product and fertilizers as the byproduct, while the drawbacks of the technology include high cost, strict startup condition and long time for fermentation [9-12]. Landfill is a traditional method with the disadvantages of requirements on large area of land and great amount of greenhouse gas emissions. Incineration is used to produce thermal energy and can greatly reduce the volume of waste [13]. However, Chinese food waste contains a lot of water, i.e. about 80% by weight, and this largely affects the application of incineration in practice. Composting is very popular due to simple operation management and high economic efficiency [14]. Heat-moisture reaction can effectively eliminate bacteria and odor [15]. So far, the exiting studies have mainly studied a single method regarding its associated impacts [9, 16] or compared two methods based on a specific case study [14,17]. However, there have been very few studies comprehensively comparing the various treatment methods from a life cycle perspective.

Therefore, the paper aims to compare the five commonly used treatment methods, namely anaerobic digestion, landfill, incineration, composting and heat-moisture reaction, from a life cycle perspective. To achieve this aim, a case study was implemented in Shandong University in China to provide the data and to increase the relevance.

2. Data and Methodology

According to the ISO standard, life cycle assessment (LCA) evaluates the life cycle environmental impacts of a product or service [18]. The main processes of a LCA include: definition of goal and scope, inventory and impact assessment.

An on-site investigation was performed in the Xinglongshan Campus of Shandong University in the spring of 2016. About 2 tons of food waste is produced by around three thousand students per day in the surveyed canteen and we take it as the function unit in the LCA. The main contents of the food waste include meat (about 11%by weight), vegetable (about 42%), cereal (about 22%), water (about 15%) and others (about 10%). The food waste is sent to a treatment plant by truck and the distance between the university and the plant is about 33.1 km. The data on anaerobic digestion and other technical details in reality are collected from the interviews at Shandong SIFON Environmental Protection & New Energy Co. LTD. The LCA was implemented using Simapro and the assessment method Eco-Indicator99 was adopted.

Taking the process of anaerobic digestion as an example, Fig. 1. (a) shows the system boundary for the LCA, which starts from food waste collection, to transportation and then to anaerobic digestion. The food waste collection stage in this LCA implies the food waste collected by canteen stuff after being used for food, which means all the embedded data for the other life stages such as cultivation are not included in investigation, but come from the database i.e. EcoInvent 8.0. The processes of anaerobic digestion can be generally divided into four steps: waste crushing, three-phase separating, anaerobic digesting and dehydrating, as shown in the dotted area in Fig. 1. (a) It is assumed that the starting processes including food waste collection and transportation are the same prior to different treatments and the study thus concentrates on the differences between the treatments of food waste as shown in Fig. 1. (b).

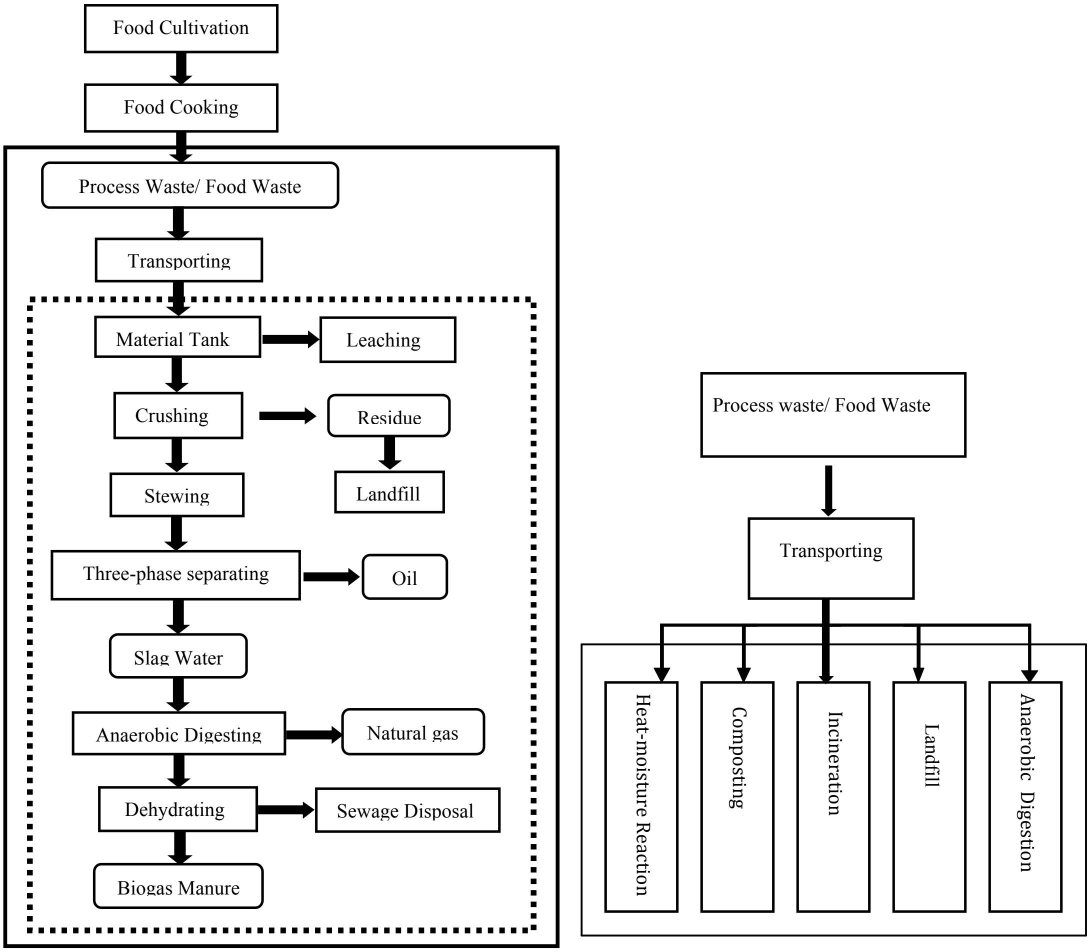

Fig. 1. (a) System boundary of waste food treatment using anaerobic digestion; (b) system Boundaries of five treatment methods

3. Life Cycle Assessment

3.1. Goal and Scope

This study first analyzed the food waste from the canteen of Shandong University and then sent for anaerobic digestion. The study investigated every stage in the treatment and calculated the environmental impacts in every stage, including climate change, acidification/ eutrophication and carcinogens. The study then evaluated and compared the five different food waste treatment methods regarding their environmental aspects.

3.2. Inventory

Table 1 shows the inventory of food waste from collection to anaerobic digestion.

Table 1. Inventory of waste food treatment by anaerobic digestion

Emissions	Substances	Total	Food waste collecting	Waste crushing	Three-phase separating	Anaerobic digesting	Dehydrating
Emissions to Air (kg/t)	CO_2	391	357.5	12.3525	0.4145	13.585	6.9276
	CO	0.6965	0.683235	5.22E-03	1.25E-04	5.82E-03	2.12E-03
	CH_4	0.098	0.067005	0.013457	1.90E-04	0.015155	1.90E-03
	H_2S	3.67E-04	3.16E-04	2.37E-05	2.68E-07	2.64E-05	2.53E-08
	NO_x	1.615	1.54	0.0264	1.01E-03	0.0295	0.0179
	SO_2	0.695	0.4635	0.0805	3.15E-03	0.09	0.0565
	VOC	1.19E-02	1.15E-02	1.38E-04	6.40E-06	1.54E-04	1.18E-04
	$PM_{2.5}$	0.0276	0.0262	6.55E-04	4.625E-06	7.40E-04	6.5E-08
Emissions to Water (kg/t)	AOX	8.70E-06	8.2E-06	2.055E-07	5.75E-09	2.20E-07	9.8E-8
	BOD	4.71E-02	4.43E-02	1.26E-03	2.085E-05	1.42E-03	6.80E-05
	COD	0.08	0.0735	4.26E-03	3.02E-05	2.03E-03	1.42E-04
	Phosphate	0.142	0.139	1.29E-03	4.845E-06	1.45E-03	1.8E-09
	Sulfate	0.3245	0.2595	0.03055	1.25E-04	0.0344	1.61E-04
	Arsenic	3.13E-05	2.615E-05	2.34E-06	1.55E-08	2.64E-06	9.75E-08
	Cadmium	2.03E-05	1.905E-05	5.9E-07	3.36E-09	6.60E-07	1.57E-08

Table 2 shows the inventory of five treatment processes. The substances we choose are of large amount and also representative under each emission category.

Table 2. Inventory of treatment processes of food waste

Emissions	Substances	Anaerobic digestion	Landfill	Incineration	Composting	Heat-moisture reaction
Emissions to Air (kg/t)	CO_2	36.54	221.35	676	42.64	48.35
	CO	0.012	0.68	0.059	0.104	0.013
	CH_4	3.05	14.70	3.12	3.06	3.05
	H_2S	5.05E-05	9.84E-04	2.44E-04	3.7E-05	0
	NO_x	0.075	0	0	0.305	0.12
	SO_2	0.23	0.14	0.087	0.087	0.37
	VOC	0.00045	0.0166	0.00245	0	0.0008
	$PM_{2.5}$	0.0014	0.0016	0.00115	0.0146	0
Emissions to Water (kg/t)	AOX	5E-07	0.085	0.0038	3.95E-06	6.5E-07
	BOD	0.0028	0.00035	0.0001	0.0377	0.00045
	COD	0.0065	0.018	0.01	0.0475	0.001
	Phosphate	0.003	0.2665	0	0.014	0
	Sulphate	0.065	0.0605	0.037	0.3405	0.001
	Arsenic	5.1E-06	3.85E-06	1.95E-06	4.7E-05	1.15E-06
	Cadmium	1.25E-06	9.5E-07	1.15E-06	2.0E-05	1E-07

3.3. Impact Assessment Results

The study aggregated the impacts into three categories: climate change, acidification/ eutrophication and carcinogens and the results are shown in Table 3. For each category, only the three types of substances with the highest impacts are considered.

From Table 3, food waste collection has the most impact especially in climate change and acidification/ eutrophication, which is 90.9% and 96.2%. It is reasonable because food waste in LCA contains the food's life cycle stages with intensive energy and material consumption such as cultivation, manufacture, distribution and cooking. As for the rest two processes, transport and disposal has almost the same impact. In the transportation, the magnitude of impacts is dependent on the distance of transport. In this research, the distance from university to waste treatment plant is 33.1km. However, if a treatment facility were located close to the campus, the impacts of transportation would significantly decrease. In the disposal process, three-phase separating has higher environmental impacts, thus more worthy of further considering.

Table 3. Environmental impacts of food waste case study

Impacts	Substances	Total	Food waste collecting	Transporting	Waste crushing	Three-phase separating	Anaerobic digesting	Dehydrating
Climate change (DALY)	CO_2	1.64E-04	1.50E-04	8.70E-06	1.74E-07	5.72E-06	5.19E-06	2.90E-06
	CO	4.36E-07	4.28E-07	0	8.05E-11	3.66E-09	3.27E-09	1.36E-09
	CH_4	2.73E-05	2.68E-05	2.15E-07	4.38E-09	1.99E-07	1.78E-07	6.65E-08
Acidification/ Eutrophication ($PAF*m^2yr$)	Ammonia	105.63	105.628	6.05E-04	4.60E-06	1.25E-03	1.12E-03	4.22E-05
	NO_2	2.171	2.165	0	6.54E-06	1.58E-04	5.39E-03	1.21E-04
	Sulphur dioxide	1.444	0.965	0.03945	6.55E-03	0.187	0.167	0.118
Carcinogens (DALY)	Aldrin	1.85E-05	1.31E-05	1.79E-06	4.80E-09	2.87E-06	2.54E-06	0.00E+00
	Arsenic	4.11E-06	3.44E-06	5.45E-07	2.04E-09	3.47E-07	3.08E-07	1.28E-08
	Cadmium	2.89E-06	2.71E-06	3.81E-07	4.78E-10	9.38E-08	8.41E-08	2.23E-09

Table 4. Environmental impacts of food waste by different treatment methods

Categories	Substances	Anaerobic digestion	Landfill	Incineration	Composting	Heat-moisture reaction
Climate change (DALY)	CO_2	1.40E-05	9.22E-05	1.92E-05	1.66E-05	1.91E-05
	CO	8.38E-09	4.40E-07	3.75E-08	6.73E-08	8.98E-09
	CH_4	4.50E-07	1.03E-04	1.10E-06	5.51E-07	4.39E-07
	Total	1.44E-05	1.96E-04	2.04E-05	1.74E-05	1.94E-05
Acidification/ Eutrophication ($PAF*m^2yr$)	Ammonia	2.20E-03	6.21E-03	0.405	2.72E-02	6.00E-05
	NO_2	6.03E-03	3.482	7.184	3.58E-04	1.15E-03
	Sulphur	0.479	0.289	0.184	0.179	0.775
	Total	1.71042	3.77788	7.77311	3.67501	2.80491
Carcinogens (DALY)	Aldrin	4.88E-08	4.88E-08	4.88E-08	5.46E-06	2.46E-05
	Arsenic	8.38E-08	2.51E-07	4.83E-07	6.69E-07	6.16E-06
	Cadmium	1.43E-08	1.59E-07	3.46E-07	1.80E-07	2.90E-06
	Total	6.62299E-06	1.07033E-06	8.03563E-07	3.48534E-05	4.99539E-07

Table 4 shows the comparison between different treatment methods and the findings are summarized as follows.

- For the impact on climate change, anaerobic digestion has the lowest impacts in the five treatment methods and it is followed by composting, heat-moisture reaction and incineration. In contrast, landfill may create environmental impacts of 10 times higher than the other treatment methods. The reason is that landfill produces more greenhouse gases such as carbon dioxide and methane into the atmosphere and only 70% of carbon dioxide is collected in practical application [19].

- Anaerobic digestion may create least impacts on Acidification and Eutrophication and it is followed by heat-moisture, composting and landfill. Incineration has the highest impacts (5.5 times higher than anaerobic digestion and 2.5 times higher than landfill) mainly due to the emission of nitrogen dioxide.
- With regard to carcinogens, the ranking of the treatment methods is heat-moisture, incineration, anaerobic digestion, landfill and composting. Incineration of waste food would produce a large amount of dioxins, about twice as much as the other treatments, which is a serious type of pollution to human health [20]. Although dioxins have fewer impacts than the aldrin, arsenic and cadmium, the total magnitude of aldrin, arsenic and cadmium is not so much.

To further examine the influences of different treatment methods in the whole life cycle of food waste treatment, a synthetic analysis of the environmental impacts evaluated these five methods. And results turned out the best and worst methods are anaerobic digestion and landfill respectively. Environmental impact ratio is the proportion of treatment process in the whole life cycle stages. For climate change, acidification/ eutrophication and carcinogens, ratio of anaerobic digestion is 4.02%, 1.33% and 22.62% while landfill is 36.28%, 2.89% and 4.51%. It indicates that different disposal methods make sense when considering climate change and carcinogens, while there is no much difference in acidification or eutrophication.

4. Conclusion

The study employed a life cycle assessment to compare various treatment methods for handling food waste and a canteen in Shandong University, China, was investigated as the data source. The main findings are summarized as the following:

- The most effective way to reduce environmental impacts of food waste is to save food and avoid waste, since food preparation and waste collection (please check my comments before, and the terms here should be the same as “food & collection”) accounts for the largest proportion of environmental impacts, regardless what treatment method is used.
- The study also found that transportation would be an important source of pollution. Therefore, a waste treatment plant might be built not too far away from the place where a large number of office and school canteens and restaurants are located nearby. It would help to reduce the overall environmental impacts.
- Landfill occupies large area and the impact on global warming is huge therefore the usage of it should be reduced. Incineration is inclined to causing acid rain and eutrophication. And among the remaining three new technologies, based on the features of food waste, anaerobic digestion has more advantages. As a preferred choice to treat food waste, the processes of anaerobic digestion, like three-phase separating process, can be optimize to further reduce the environmental impact.

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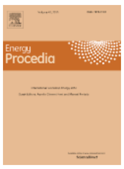

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