Environmental Science and Pollution Research (2019) 26:10374–10386
https://doi.org/10.1007/s11356-019-04454-1

RESEARCH ARTICLE

The economic and environmental benefits analysis for food waste anaerobic treatment: a case study in Beijing

Xiaopeng Guo[1,2] · Xiaoyu Yang[1]

Received: 2 August 2018 / Accepted: 3 February 2019 / Published online: 14 February 2019

Abstract
The disposal of food waste has attracted worldwide attention. Each year, the amount of wasted food accounts for an estimated one third of annual food production globally. This large amount of food waste has caused serious land, water, and air pollution. In the past, most research on food waste was focused solely on food waste disposal processing. Only a few studies analysed the flow of materials in food waste treatment processes. Therefore, this paper focused on the process of food waste anaerobic treatment in Beijing and investigated the treatment. According to a life cycle theory, the food waste treatment process is divided into three processes: "collection and transportation, disposal, and resource utilization." This paper analysed the input and output of food waste treatment in different processes and evaluated the economic and environmental costs and benefits of food waste treatment. The study found that 200 t of food waste anaerobic treatment can obtain benefits 66,888 Chinese yuan, generate electricity energy 43,350 kW·h, and reduce carbon dioxide emissions 16,087 kg. Generally, the economic and environmental benefits of the food waste anaerobic treatment project are considerable. However, the economic benefits are mainly from government subsidies. There are many impurities in food waste, which indicates some problems in food waste treatment. Thus, the proposals to strengthen waste classification, optimize the layout of garbage collection and transportation, and accelerate the development of waste treatment plants have been put forward.

Keywords Food waste · Anaerobic treatment · Life cycle · Input and output · Economic benefits · Environmental benefits

Introduction

There is a growing worldwide concern over food waste disposal. As a super-consumer city, Beijing produces a large amount of food waste every year. The annual food waste production is increasing rapidly. Due to the lack of proper treatment, food waste has not only caused a waste of resources but has also caused serious land, water, and air pollution. Thus, the collection and disposal of food waste fulfils resource recycling requirements, in addition to the requirement to reduce its harm. At present, food waste treatment methods mainly include landfilling, incineration, composting, anaerobic digestion, and animal feed. Anaerobic treatment is a treatment method with advanced treatment technology and excellent economic benefits. Beijing Dongcun Integrated Processing Plant of Classified Waste is the first enterprise using anaerobic fermentation technology to treat food waste in China. This plant has advanced processing technology and treatment process. Hence, the Dongcun food waste treatment plant is a suitable site for studying food waste disposal.

Overall, the food waste output in China has shown an increasing trend. Through an analysis of the food waste output in Chengdu from 2001 to 2010, researchers found a striking growth of food waste production in the city and predicted that the food waste output in Chengdu would reach 514.96 t/day in 2010 (Meng and Huang 2010). The factors affecting food waste production stem from all aspects, such as population, culture, politics, and economics (Thyberg and Tonjes 2016; Liao et al. 2018). Of all factors, population has the greatest impact on food waste output (Wang et al. 2013). Food waste output presents spatial and temporal patterns. In time, waste

Responsible editor: Philippe Loubet

✉ Xiaoyu Yang
yxyxiaoyu2016@163.com

[1] School of Economics and Management, North China Electric Power University, Hui Long Guan, Chang Ping District, Beijing 102206, China

[2] Beijing Key Laboratory of New Energy and Low-Carbon Development, North China Electric Power University, Hui Long Guan, Chang Ping District, Beijing 102206, China

production not only presents seasonal characteristics but also has a commonality with weekly production distribution. In space, the amount of food waste is greater in areas with higher population density than in places with more scattered residents (Xiao 2015). However, urban residents produce more waste than rural residents (Secondi et al. 2015). Food waste composition varies according to regional eating habits. In Beijing, vegetables account for the highest proportion of waste, at approximately 43.16%, followed by meat at 20.59% and staple foods at 16.66% (Zhang et al. 2016). In food production and consumption, changing dietary habits and reducing waste at all stages of the food chain can effectively reduce resources waste (Laurentiis et al. 2016). In general, production of food waste is increasing; wasted food indicates a waste of energy and resources.

Food waste not only leads to an increase in resource inputs for treatment but also causes the loss of various resources for the production, transportation, processing, and storage of food. Reutter et al. (2017) applied input–output methodology to estimate the impact of food waste in Australia. They found that food waste represents 9% of total water use and 6% of green house gas (GHG) emissions. Food waste can increase carbon emissions. In Chinese households, each person wastes an average of 16 kg of food per year, which is equivalent to an increase of 40 kg of carbon dioxide emissions (Song et al. 2015a). The carbon emissions vary widely according to food and diet structures. Animal products have greater carbon emissions than plant-based foods during production (Xu and Lan 2016). The diet model mainly based on animal products has the highest global warming potential (Veeramani et al. 2017). Reducing waste is the optimal way to use resources and process waste.

Of food waste treatments, anaerobic fermentation shows considerable economic benefits and energy utilization and is the most favoured food waste treatment. In China, the anaerobic fermentation treatment of food waste has shown obvious advantages in terms of the ecological environment, economic benefits, resource utilization, and carbon emissions (Zhang et al. 2012; Liu et al. 2016; Hao et al. 2017). Anaerobic digestion has also performed well in other regions. In Ireland, compared with incineration and composting, anaerobic digestion has the lowest environmental impact and the best return on carbon investment (Oldfield et al. 2016). Anaerobic digestion and composting can effectively recover energies when using different foods to research carbon emissions (Eriksson et al. 2015). Compared with biodiesel, anaerobic digestion shows the best cost-effectiveness, when considering the local environmental impact (Ahamed et al. 2016). However, these studies were only focused on food waste anaerobic digestion process. Anaerobic treatment of food waste is not suitable for all areas. Due to the unique food culture in Chongqing, the comprehensive benefits of small-scale food waste disposal stations are optimal (Li et al. 2013). In Taiwan, food waste composting produces the most net income (Chen 2016). In Suzhou Jiangsu Province, a project that uses a variety of methods to treat food waste also represents good resource use and economic benefits (Wen et al. 2016). There are some problems with the anaerobic treatment of food waste, such as low biogas production (Clercq et al. 2016, 2017a), deficiencies in major processes (Clercq et al. 2017b), and insufficient policies (Clercq et al. 2017c).

In China, the food waste treatment industry has achieved certain developments, but there are still many problems. Waste classification can make disposal much more convenient (Lo and Woon 2016), but the economic cost increases when the waste collection changes from mixed to classified (Jiang et al. 2012). In Beijing, there are many problems with the food waste treatment system, such as the high transportation costs, inadequate operating mode of the resource-processing industrial chain and lack of retrospective supervision measures (Liu 2014; Liu et al. 2017). There is a complex interest game between the food waste producers, third-party waste disposal companies, and government departments (Wu 2015). To prevent the occurrence of illegal activity and effectively control the transportation process of food waste, advanced technologies such as the Internet of Things, geographic information systems (GIS) and wireless communication should be introduced into the food waste management platform (Shang et al. 2013). Although much importance has been attached to food waste treatment, this attention is far from adequate.

Some studies have used the life cycle assessment method to evaluate food waste treatment methods. Nevertheless, most of these studies used comparative analysis to compare the similarities and differences of food waste treatment methods. For example, Tan et al. (2015a) comparatively analysed the energy recovery, economic benefits and environmental impacts of landfill gas recovery, incineration, anaerobic digestion, and gasification in Malaysia. Using energy recovery efficiency as the evaluation standard, Arafat et al. (2015) found the most suitable treatment for different waste types. Opatokun et al. (2017) used the life cycle method to compare the environmental impacts of different food waste treatments, such as landfilling and anaerobic digestion. Additionally, some studies using life cycle methods analysed the material flows in the process of food waste treatment. Miah et al. (2017) studied a household waste processing system that combined dry anaerobic digestion with composting and found the carbon flow in this system. There were fewer researchers of the life cycle assessment to analyse the flow of materials in food waste treatment processes.

From the perspectives of economic benefits, environmental benefits, and resource recovery, anaerobic digestion is a better treatment method. In the past, food waste research was focused on waste disposal, comparatively analysing the economic and environmental costs and benefits of different treatment methods. Therefore, this paper analysed the food waste life cycle from collection and transportation to disposal to resource utilization processes. First, this paper focused on the Beijing Dongcun Integrated Processing Plant of Classified Waste, investigated the current situation of food waste from production to resource utilization, and obtained the basic research data through field research and data collection. Second, by respectively analysing the economic and environmental input and output of food waste treatment in the three processes of food waste treatment, the material flow of food waste treatment was acquired. Finally, based on the investigated situation and research results, this paper puts forward suggestions for the future development of the food waste treatment industry in Beijing.

Research projects and data

Introduction of the Beijing Dongcun integrated processing plant of classified waste

According to statistics from the Beijing Urban Management Committee, in Beijing in 2017, there were 11 companies operating in the collection and transportation of food waste, 10 food waste disposal stations, and 30 on-site treatment facilities in government offices and schools. In response to the increase in food waste production, the Beijing government plans to build five food waste treatment plants by 2020. At present, the main food waste treatment plants in Beijing include Gao'antun food waste treatment plant, Nangong food waste treatment plant, and Dongcun Integrated Processing Plant of Classified Waste. Dongcun Integrated Processing Plant of Classified Waste is a subsidiary company of Beijing Environmental Sanitation Engineering Group Co., Ltd. Dongcun Integrated Processing Plant of Classified Waste is located in Dongcun, Taihu Town, Tongzhou District, Beijing. This large-scale waste treatment plant integrates food waste treatment, domestic rubbish disposal, and diseased animal and medical waste treatment. The Dongcun food waste treatment plant is one of the most advanced waste treatment facilities in China. The plant covers 23,459 m^2 with a total investment of 184.19 million Chinese yuan (CNY) and operates in the build-operate-transfer (BOT) mode. The total designed processing capacity is 650 t/day, including 150 t/day for community sorted waste, 300 t/day for urban domestic waste, and 200 t/day for food waste. The area in the red box in Fig. 1 is the Dongcun Integrated Processing Plant of Classified Waste (for convenience, we use "Dongcun food waste treatment plant" to refer to the food waste treatment project at the Dongcun Integrated Processing Plant of Classified Waste). The Dongcun food waste treatment plant uses anaerobic fermentation to treat food waste, effectively reducing the amount of organic matter in the waste. The biogas produced by fermentation is eventually converted into electrical energy, which greatly reduces greenhouse gas emissions and realizes resource recycling. The food waste treatment project involves advanced processing technology and mature technology.

Research data on food waste in the processes of collection and transportation, disposal, and resource utilization

Research data on the food waste collection and transportation process

Food waste is handled through the three processes of collection and transportation, disposal, and resource utilization. This paper has investigated the operation of the Dongcun food waste treatment project and introduced herein the processing steps for food waste in the three processes. This food waste treatment project currently has a processing capacity of 200 t/day, and after expansion, the processing capacity is expected to increase to 400 t/day. This project mainly handles food waste sourced from schools, catering companies, and government offices in Chaoyang, Dongcheng, Xicheng, Shunyi, and Tongzhou districts. The plant location and collection area are shown in Fig. 2. The shaded area indicates the collection and transportation area of the Dongcun food waste treatment plant.

After a meal service, each catering company collects food waste and places it into a special bucket, pending collection by a food waste truck. The trucks regularly collect food waste at designated locations every day. When a truck is full, it returns to the plant for unloading. The collection mode is shown in Fig. 3. The food waste trucks are special operation vehicles, each with a total weight of 8275 kg and a load capacity of 3490 kg. The trucks collect and transport food waste from 5 am to 9.30 pm every day. There are 14 trucks and 40 operators, including drivers and vehicle maintenance staff.

Research data of food waste disposal process

After collection, food waste is transported directly to the plant for processing. Every day at 7.30 am, trucks begin entering the plant, and the trucks finish by 10.30 pm. The food waste treatment project has 50 workers, including operators and equipment serviceman. Additionally, the workers operate in two shifts. The Dongcun food waste treatment plant disposes of approximately 200 t of food waste per day. The water content of food waste is approximately 70–80%. When a truck enters the plant, it is weighed; when leaving the plant, the truck is weighed again to determine the daily disposal amount of food waste. After weighing, each truck enters the plant to unload the food waste into the discharge pit. The food waste in the discharge pit is conveyed through a screw transfer machine. Then, sequentially, bags are removed, and the screening process occurs. After screening, the food waste

Fig. 1 The plan of Dongcun integrated processing plant of classified waste

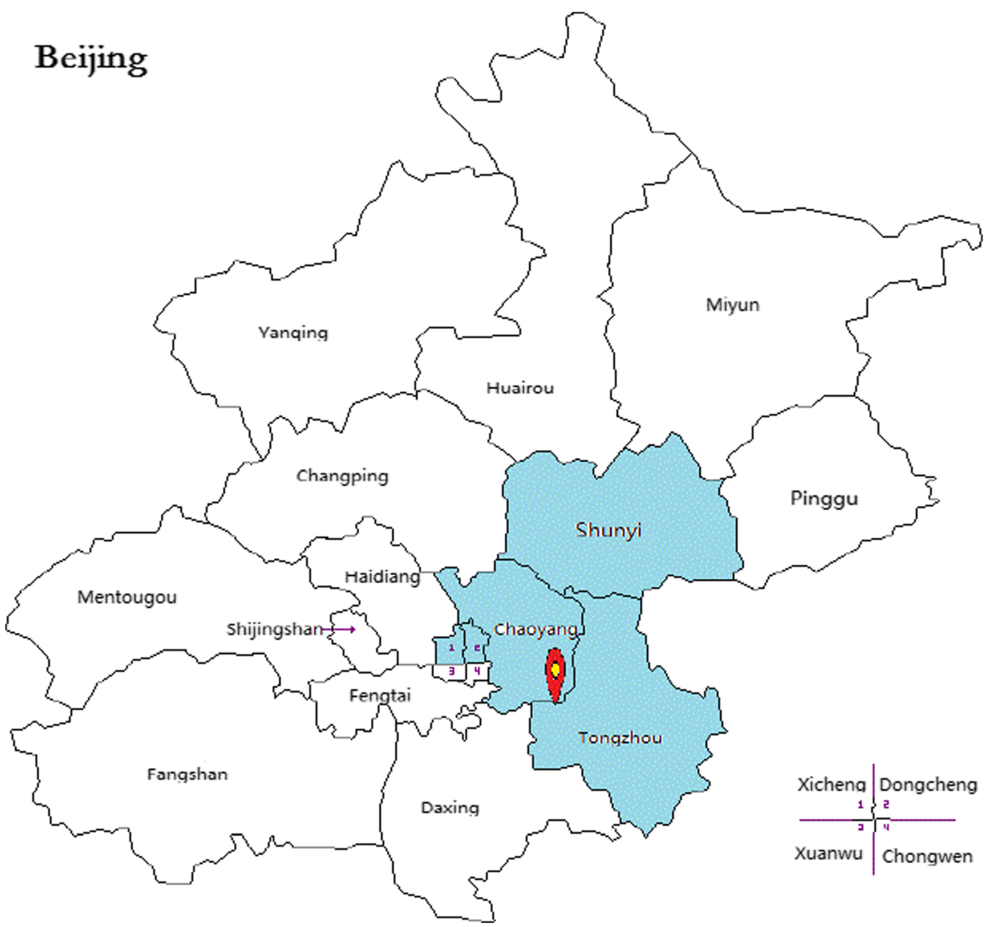


Fig. 2 The scope of collection and transportation

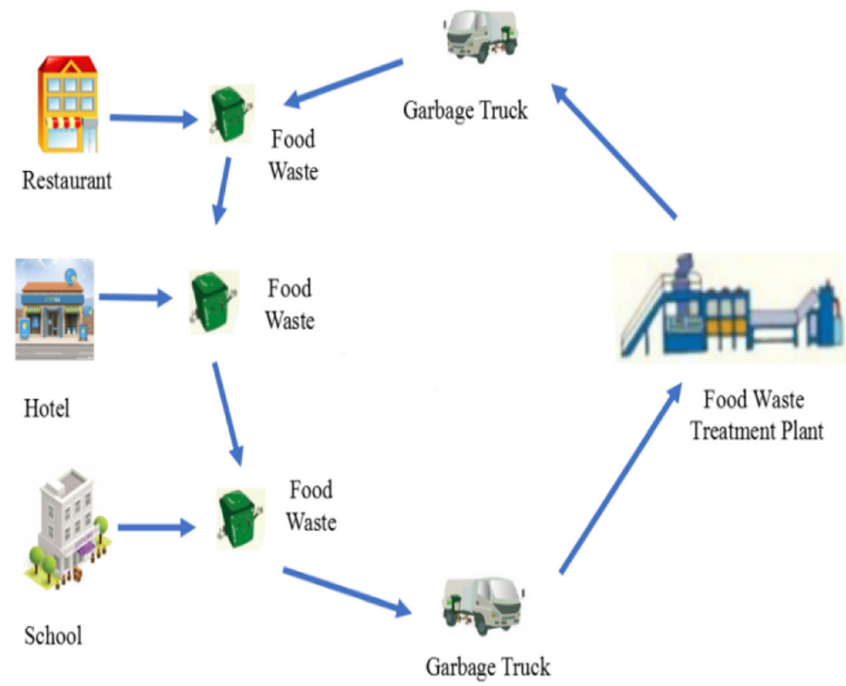


Fig. 3 The collection mode

is divided into two parts: the oversize and the undersize. The oversize consists of material that cannot pass through the screening hole, mainly including plastic bags, beverage bottles, chopsticks, and other effects. Because the oversize is mixed with waste, it is contaminated and cannot be recycled, and thus, can only be landfilled. Due to the food waste quality variation, the weight of the impurities slightly fluctuates. The quantity of impurities accounts for approximately 10% of the total waste, approximately 20 t/day. The undersize consists of the material that passes through the screening hole, which continues on to be crushed and pulped. Finally, this material is piped into the fermenter for anaerobic fermentation. The fermentation is performed at 35 °C during 20 days. The project has two fermenters with a monomer volume of 5000 m^3. When the two fermenters are fully utilized, the daily disposal capacity is expected to reach 400 t. The final products of the food waste anaerobic fermentation treatment are biogas, biogas residue, and leachate. The system produces approximately 30 t of biogas residue, 110 t of leachate, and 30,000 m^3 of biogas every day. The biogas is mainly composed of CO, CO_2, H_2S, and CH_4, and the combustible gas content is about 45–55%. The biogas is sent to the biogas purification system for purification. The gas purification system simultaneously collects biogas from other processing systems. The gas purification system can purify 2000 m^3 of biogas per hour. This system uses biological desulfurization technology to separate H_2S from biogas. During the operation, there are no other substances added to the system and without any additional costs.

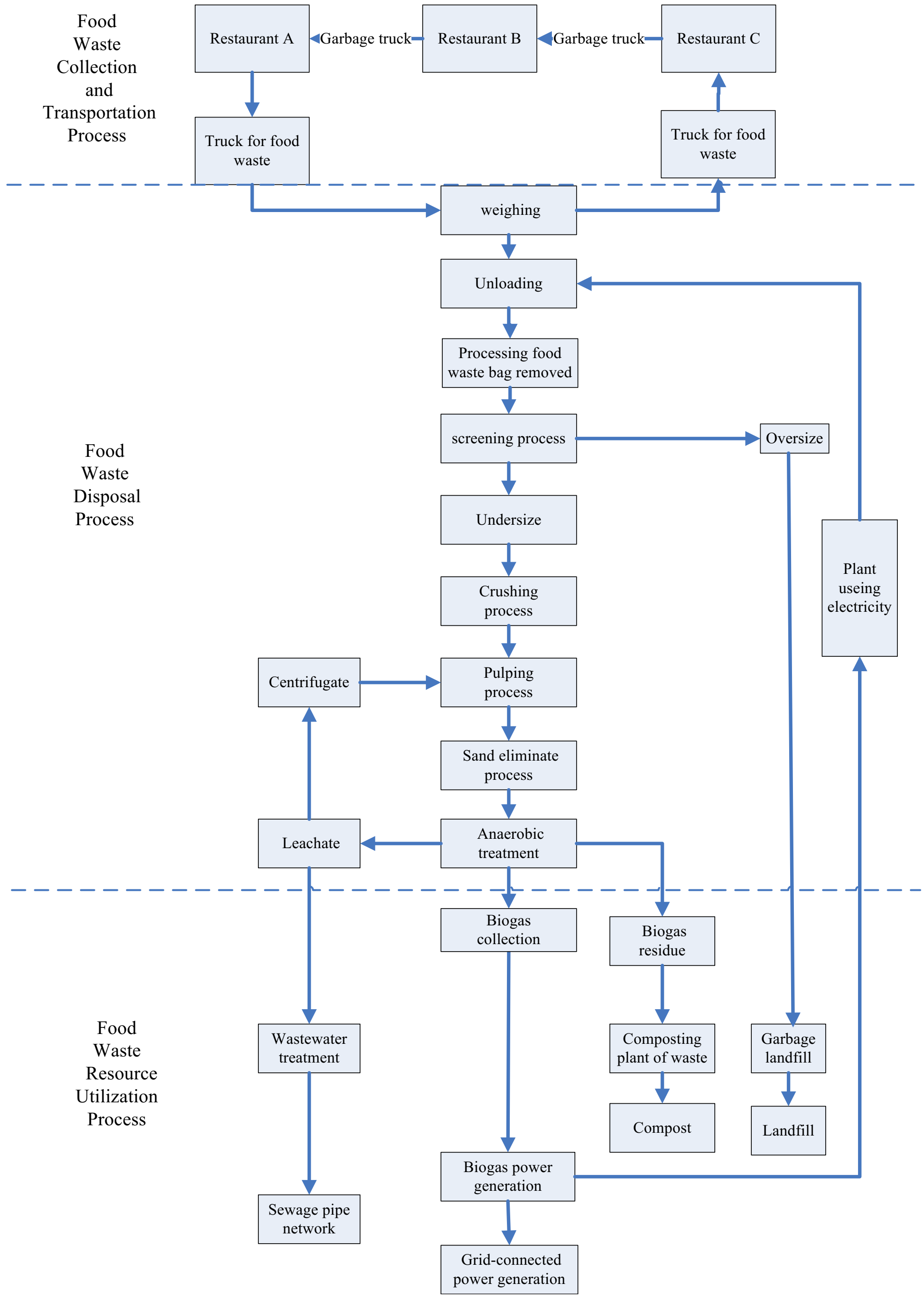
The basic data of food waste resource utilization process

This process utilizes the products of anaerobic fermentation. Biogas is used to generate electrical power. According to statistics, 1 m^3 of biogas can generate approximately 1.5 kW·h of electricity. The power generated is connected to the grid for power supply, except for that used by the plant. The biogas residue is transported to the Nangong food waste treatment plant for composting into plant fertilizer. About 7–15% percentage of the leachate enters the pulping process. The other portion enters the wastewater treatment system and is discharged into the sewage pipe network after treatment. In addition, the oversize material is transported to the An'ding Landfill for landfilling. The processing flow of the food waste is shown in Fig. 4. The Dongcun food waste treatment plant utilizes the biological deodorization method. The biological deodorization system accesses to nutrition by treating the odour in the air. During the biological deodorization system operation, there are no other substances added. The biological deodorization system also does not generate costs during operation.

The economic and environmental cost-benefit analysis of the collection and transportation, disposal, and resource utilization processes

Food waste treatment can be divided into three processes: collection and transportation, disposal, and resource utilization. According the input and output of each process, the economic and environmental costs and benefits of the life cycle of food waste treatment were calculated. In the processes of

Fig. 4 The processing flow of the food waste



collection and transportation, disposal, and resource utilization, the inputs include human labour, fuel, electricity and other resources, and the outputs include carbon dioxide, wastewater, and impurities. This paper combined the material flow analysis, the economic cost-benefit analysis with the environmental cost-benefit analysis and carried out a more in-depth study of food waste treatment.

According to the regulations of the Beijing Municipal Commission of Development and Reform, the food waste treatment plant charges the catering companies 100 CNY/t (including collection, transportation, and disposal). In China, the government subsidizes the food waste disposal process at a price of 110 CNY/t, subsidizes the collection and transportation process at a price of 100 CNY/t, and subsidizes the companies that integrate disposal and transportation at a price of 210 CNY/t. These incomes should be considered in the economic cost-benefit analysis. In practice, the processes of collection and transportation and disposal are handled by different companies. In order to analyse the economic and environmental costs and benefits of the full life cycle of food waste treatment, the three processes were considered as a whole. At present, the Dongcun food waste treatment plant is being expanded. The procurement cost and equipment depreciation cannot be accurately calculated. Considering the accuracy of the analysis, this paper mainly analysed the operating economic and environmental costs. Based on the average wage in Beijing in 2017, this paper assumed that the average wage of the workers for food waste treatment is approximately 7247 CNY/month, which mean the daily wage is 241.56 CNY. Based on fuel prices in Beijing, the price of 1 liter of fuel is approximately 7 CNY.

The economic and environmental cost-benefit analysis of the collection and transportation process

In the process of the collection and transportation of food waste, the main factors involved are the inputs of human labour and fuel and the output of automobile carbon dioxide. The food waste at Dongcun food waste treatment plant mainly originates from the districts of Dongcheng, Xicheng, Chaoyang, Tongzhou, and Shunyi. There are 200 t of food waste collected and transported every day. When a vehicle is empty, the fuel consumption is approximately 8 L per 100 km. When a vehicle is full, the fuel consumption is approximately 11 L per 100 km. There are 14 trucks and 40 operators, including drivers and vehicle maintenance staff.

The output of food waste is closely related to the population size. This paper has assumed that the proportion of food waste in the five districts is same as the proportion of the population. According to the 2017 Beijing statistical yearbook, the population levels of permanent residents of Dongcheng, Xicheng, Chaoyang, Tongzhou, and Shunyi districts were 0.878, 1.259, 3.856, 1.428, and 1.075 million, respectively. The amounts of food waste collected in the five districts respectively are 20.7, 29.6, 90.8, 33.6, and 25.3 t/day. The distance from the centre of the five districts to the plant was set as the transportation distance of the food waste. The transportation distances are 22, 26, 18, 20, and 35 km for Dongcheng, Xicheng, Chaoyang, Tongzhou, and Shunyi, respectively. The basic data on the food waste collection and transportation process is shown in Table 1.

The economic benefits analysis

The costs in the collection and transportation process mainly include human labour and fuel. Based on the average wage and fuel prices in Beijing, food waste transportation consumes 243.01 L of fuel and the cost of fuel is 1701.07 CNY every day. The labour cost of food waste collection and transportation is 9662.8 CNY. Thus, the daily cost of the food waste collection and transportation process is 11,363.87 CNY. The cost of human labour accounts for 85.03% of the total cost and is the main source of the total cost. The economic costs are shown in Table 2.

The income of the collection and transportation process mainly includes government subsidies and catering companies processing fees. The government subsidy for the collection and transportation of food waste is 100 CNY/t. Every day, the collection and transportation process obtains government subsidies totalling 20,000 CNY. The processing fee charging from catering companies for transportation and disposal processes is 100 CNY/t. Every day, the transportation and disposal processes obtain processing fees totalling 20,000 CNY. Every day, the total income from the food waste collection and transportation process is 40,000 CNY. The economic incomes are shown in Table 3.

The environmental benefits analysis

Food waste is collected by the special bucket with lid, and transported by food waste trucks in an enclosed manner. The enclosed manner of collection and transportation has prevent food waste to produce air pollution. In this process, the amount of gas released from the food waste is small and imponderable. Hence, this paper does not analyse it. The environmental impact of the collection and transportation process consists of the carbon dioxide of the trucks. According to statistics from the Carbon Emissions Trading Network in China, consuming 1 L of diesel emits 2.63 kg of CO_2 equivalent. The collection and transportation process emits 639.12 kg of CO_2 equivalent every day.

Table 1 The basic data of food waste collection and transportation process

District	Population (thousand)	Proportion (%)	Weight (t/day)	Times	Transport mileage (km)	Fuel consumption (L)
Dongcheng	878	0.103	20.7	6	22	25.08
Xicheng	1259	0.148	29.7	9	26	44.46
Chaoyang	3856	0.454	90.8	26	18	88.92
Tongzhou	1428	0.168	33.6	10	20	38
Shunyi	1075	0.127	25.3	7	35	46.55

Table 2 The economic costs of food waste collection and transportation

Cost item	Amount	Unit cost	Cost[a] (CNY/day)
Fuel cost	243.01 (L/day)	7 (CNY/L)	1701.07
Labour cost	40	241.57 (CNY/day)	9662.67
Total cost[b]			11,363.74

[a] Cost = amount × unit cost

[b] Total cost = fuel cost + labour cost

The economic and environmental cost-benefit analysis of the disposal process

In the Dongcun food waste treatment plant, food waste flows through a screw conveyor and pipeline, which work by electricity. So, the food waste disposal process only consumes human labour and electrical energy. Moreover, the electrical energy is generated by the utilization of biogas.

The economic benefits analysis

In the food waste disposal process, this paper has only needed to analyse the cost of human labour and electrical energy. There are 50 workers in the Dongcun food waste treatment plant. Based on the average wage in Beijing, the labour cost of the food waste disposal process is 12,078.5 CNY/day. According to the power of the equipment, the total power consumed by the plant when operating is approximately 110 kW·h. The plant operates for 15 h/day, and the electrical energy consumed is approximately 1650 kW·h/day. However, the plant uses electricity produced by itself. Thus, there is no cost.

The income from the disposal process also mainly originates from government subsidies and processing fees. The processing fee has already been calculated in the process of collection and transportation. The government subsidy for the food waste disposal process is 110 CNY/t. Every day, the plant obtains subsidies totalling 22,000 CNY. The income and cost of this process are shown in Table 4.

The environmental benefits analysis

According to the characteristics of food waste anaerobic treatment, the environmental impact of disposal process mainly includes the emissions of food waste and the CO_2 produced by plant-used electricity. Outside the plant, the food waste smell is completely imperceptible. Even inside the plant, the odour is also faint, so the emissions of food waste are assumed to be negligible. The plant uses biological technology to deodorize the odour in the air. The deodorization system was injected with sufficient bacteria and culture fluid during construction. When used, the biological deodorization system can achieve self-sufficiency, which does not produce indirect emissions. The plant-used electricity is produced by the biogas. The CO_2 emissions from the plant-used electricity are deducted when evaluating the CO_2 emissions reduced by biogas power generation in the resource utilization process. Hence, environmental costs of the disposal process are assumed to be zero.

The economic and environmental cost-benefit analysis of the resource utilization process

Resource utilization includes the treatment and reuse of biogas, biogas residue, leachate, and the oversize. According to the treatment of the products described in "Research data on food waste in the processes of collection and transportation, disposal, and resource utilization", in this process, the main economic costs and benefits include the income and cost of the products. Biogas is a type of greenhouse gas. The main component of biogas is methane, which is a greenhouse gas. Biogas power generation can reduce the use of coal and the greenhouse gas emissions. Thus, this paper uses the carbon dioxide emitted by coal-fired power as the carbon dioxide reduction for biogas power generation. The environmental costs and benefits mainly include the carbon emission reduction of biogas power generation and the carbon emissions from transported biogas residue and oversize.

The Dongcun food waste treatment plant produces approximately 30 t of biogas residue, 110 t of leachate, 30,000 m^3 of biogas, and 20 t of oversize every day. According to statistics, 1 m^3 of biogas can generate approximately 1.5 kW·h of electricity. The plant can generate 45,000 kW·h of electricity per day. Except for the plant-used electricity of 1650 kW·h, the plant can supply approximately 43,350 kW·h of electricity per day to the city with electrified wire netting. The Dongcun food waste treatment plant is approximately 17 km from the

Table 3 The economic incomes of food waste collection and transportation

Income item	Amount (t/day)	Unit income (CNY/t)	Income [a] (CNY/day)
Transportation subsidies	200	100	20,000
Processing charges	200	100	20,000
Total income[b]			40,000

[a] Income = amount × unit income

[b] Total Income = transportation subsidies + processing charges

Table 4 The economic incomes and costs of food waste disposal

Economic income			Economic cost		
The amount of processing(t/day)	Processing subsidies(CNY/t)	Total processing subsidies[a] (CNY/day)	Number of workers	Salary (CNY/day)	Labour cost[b] (CNY/day)
200	110	22,000	50	241.57	12,078.33

[a] Total processing subsidies = the amount of processing × processing subsidies

[b] Labour cost = number of workers × salary

Nangong food waste treatment plant and 35 km from the An'ding Landfill. Both the biogas residue and the oversize are transported by trucks with a load capacity of 10 t. When a vehicle is empty, the fuel consumption is approximately 11 L per 100 km. When a vehicle is full, the fuel consumption is approximately 16 L per 100 km. The transportation work is done by plant workers.

The economic benefits analysis

The economic costs and benefits mainly include two parts: processing costs and product income. This paper has evaluated the income from electricity generation and compost. The feed-in tariff for biomass power generation is 0.75 CNY/kW·h. The income from food waste power generation is 32,512.5 CNY/day. The fertilizer rate from the Nangong food waste treatment plant is 26%. In all, 30 t of biogas residue can produce 7.8 t of fertilizer. The price of plant-based organic fertilizer is approximately 300 CNY/t. The revenue from biogas residue composting is 2340 CNY/day. The income generated in the process of resource utilization is 34,852.5 CNY/day. The incomes are shown in Table 5.

The product processing costs were evaluated. The leachate is treated with biofilm, and the wastewater treatment cost is approximately 0.8 CNY/t (Tan et al. 2015b). So, the leachate treatment cost is 88 CNY/day. The cost of landfilling in Beijing is approximately 110 CNY/t (Song et al. 2015b). Thus, the landfill cost for the oversize is 2200 CNY/day. The cost of sludge composting in Beijing is 133.5 CNY/t (Zhang et al. 2006). This figure was used as the cost of food waste composting. Therefore, the composting cost of the biogas residue is 4005 CNY/day. The transportation of biogas residue and the oversize consumes 32.67 L of fuel and costs 228.69 CNY/day. For the resource utilization process, the total cost is 6512.69 CNY/day. The economic cost analysis is shown in Table 6.

The environmental benefits analysis

For the resource utilization process, the environmental costs and benefits mainly include the reduced CO_2 emissions of biogas power generation, the CO_2 emissions of transported biogas residue and oversize, and the CO_2 emissions of disposed the biogas residue, oversize, and leachate. The CO_2 emissions of coal-fired power have been used as the biogas emission reduction rate. According to statistics from the Carbon Emissions Trading Network in China, each kilowatt hour of electrical energy burns 0.4 kg of standard coal, producing 0.997 kg of CO_2 equivalent. Every day, the Dongcun food waste treatment plant supplies 43,350 kW·h of electrical energy, which is saving the equivalent of 17,340 kg of coal and reducing 43,219.95 kg of CO_2 equivalent. The transportation of biogas residue and the oversize consumes 32.67 L of fuel and produces 85.92 kg of CO_2 per day. The CO_2 equivalent emissions of wastewater treatment are approximately 0.39 kg/t for a food processing wastewater treatment plant in Canada (Shahabadi et al. 2010). Every day, 110 t of leachate treatment emits 42.9 kg of CO_2 equivalent. Removing the CO_2 emissions reduced by the fertilizer, the CO_2 equivalent emissions of food waste composting are approximately 337.7 kg/t (Du et al. 2010). Every day, 30 t of biogas residue composting emits 10,131 kg of CO2 equivalent. Hao et al. (2017) pointed out that 3930 t of food waste landfilling generated 3190 t of CO_2 equivalent, which means the CO_2 equivalent emissions of food waste landfilling are approximately 811.7 kg/t. Every day, 20 tons of oversize landfilling emits 16,234 kg of CO_2 equivalent. In the resource utilization

Table 5 The economic incomes of resource utilization process

Income item	Amount	Unit income	Income[a] (CNY/day)
Power generation revenue	43,350 (kW·h/day)	0.75 (CNY/kW·h)	32,512.5
Compost income	7.8 (t/day)	300 (CNY/day)	2340
Total income[b]			34,852.5

[a] Income = amount × unit income

[b] Total income = power generation revenue + compost income

Table 6 The economic costs of resource utilization process

Cost item	Amount	Unit cost	Cost[a] (CNY/day)
Compost cost	30 (t/day)	133.5 (CNY/t)	4005
Landfill cost	20 (t/day)	110 (CNY/t)	2200
Fuel cost	32.67 (L/day)	7 (CNY/L)	228.69
Leachate treatment cost	110 (t/day)	0.8 (CNY/t)	88
Total cost[b]			6521.69

[a] Cost = amount × unit cost

[b] Total cost = compost cost + landfill cost + fuel cost + leachate treatment cost

process, the total CO_2 emission is 26,493.82 kg/day and the total amount of reduced CO_2 is 16,726.13 kg/day. The environmental cost analysis is shown in Table 7.

Results and discussion

Through the input and output analysis of the collection and transportation, disposal, and resource utilization processes, this paper has obtained an economic cost-benefit analysis table, which is shown in Table 8, and an environmental cost-benefit analysis table, which is shown in Table 9. The operating profit of the Dongcun food waste treatment project is approximately 66,888 CNY/day. Compared with the landfill gas power generation project with a daily processing capacity of 750 t and an operating profit of 46,082 CNY, the unit economic benefit of food waste anaerobic treatment is good (Zhang 2018). However, government subsidies are the main source of income, which account for approximately 43.37% of the total revenue. If the government no longer subsidizes the waste disposal project, the profit is reduced to 37.20% of the operating profit. In China, waste resource recycling is a developing industry. Of the project costs, the labour costs account for the largest proportion, approximately 72% of the total cost. Therefore, in the future, the main goal of the waste treatment industry is to reduce labour costs.

Table 7 The environmental costs of resource utilization process

Environmental costs item	Amount	Unit Co_2 emissions	Co_2 emissions[a] (kg/day)
Fuel cost	32.67 (L/day)	2.63 (kg/L)	85.92
Compost cost	30 (t/day)	337.7 (kg/t)	10,131
Landfill cost	20 (t/day)	811.7 (kg/t)	16,234
Leachate treatment cost	110 (t/day)	0.39 (kg/t)	42.9
Total Co_2 emissions[b]			26,493.82

[a] Co_2 emission = amount × unit Co_2 emission

[b] Total Co_2 emissions = compost cost + landfill cost + fuel cost + leachate treatment cost

Table 8 Economic benefits accounting

Process	Income (CNY/day)	Cost (CNY/day)
Food waste collection and transportation process	40,000	11,363.87
Food waste disposal process	22,000	12,078.5
Food waste resource utilization process	34,852.5	6521.69
Total income or cost	96,852.5	29,964.06
Operating profit		66,888.44

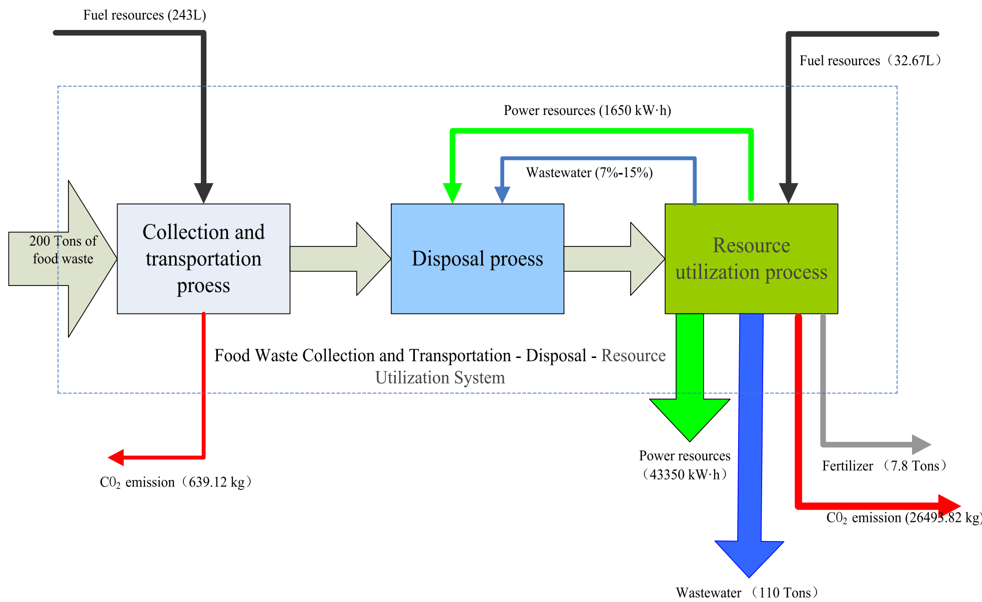
Due to the use of biotechnology, the CO_2 emissions of the project are low. By converting the carbon emissions of biogas power generation to thermal power, the project can reduce CO_2 emissions by 16,087.01 kg/day. Compared with the carbon emission offsets of landfilling and composting, this project shows good environmental benefits, which is consistent with previous research results (Hao et al. 2017). Due to the characteristics of anaerobic fermentation, in the processes of collection and transportation, disposal, and resource utilization, only a small amount of carbon emissions are caused by fuel use. The anaerobic fermentation treatment of food waste has realized waste reduction, energy reuse, and resource recycling. This treatment coincides with the requirements for green and sustainable development in China. According to the input and output analysis, a material flow chart for food waste anaerobic treatment has been drawn, which is shown in Fig. 5.

Although the environmental and economic benefits of the food waste anaerobic treatment project are considerable, according to the analysis results, there are still some problems with the anaerobic treatment of food waste in Beijing. There is still a large gap in the classification of food waste sources. The source separation of food waste is not perfect. In China, catering companies are required to classify food waste for collection. However, in the survey, this paper found that much of the waste included impurities, approximately 10% of the total food waste, such as plastic bags, chopsticks, and metal drink bottles. The food waste received by Dongcun food waste treatment plant is shown in Fig. 6. These impurities increase the cost and carbon emissions of transportation and disposal. The impurities not only reduce the resource

Table 9 Environmental benefits accounting

Process	CO_2 emissions (kg/day)	CO_2 emissions reduction (kg/day)
Food waste collection and transportation process	639.12	0
Food waste resource utilization process	26,493.82	43,219.95
Total emissions or reduction	27,132.94	43,219.95
Total reduced CO_2 emissions		16,087.01

Fig. 5 The chart of material flow for food waste anaerobic treatment



utilization efficiency of the food waste disposal system but also reduce the power generation efficiency. The government should strongly advocate for the classification of food waste and strengthen the supervision of food waste classification at catering companies. If the classification of food waste is improved, the labour and resources for food waste treatment will be significantly reduced, and the cost will also decrease. Waste is a type of resource that is put in the wrong place. A large amount of material resources can be recycled from the

Fig. 6 Food waste received by Dongcun plant

impurities. Reasonable classification of food waste can enable the reuse of these resources by residents. This change can improve the efficiency of resource utilization and reduce the carbon emissions of society as a whole.

The scope of collection and transportation by the food waste plant should be rationally planned. The food waste handled by the Dongcun food waste treatment plant originates from the districts of Dongcheng, Xicheng, Chaoyang, Tongzhou, and Shunyi. According to Fig. 2, showing the collection and transportation scope, Shunyi District is connected to Tongzhou District, where the food waste treatment plant is located. However, the transportation distance is too far. The transportation distance of some food waste has exceeded 30 km. Long-distance transportation not only increases the amount of fuel used and carbon emissions but also leads to an increased human labour investment. Therefore, rational planning of waste collection is a sensible way to reduce processing costs. Some studies have pointed out that approximately 50% of food waste in Beijing still flows to farmed animal industries or plants for illegal cooking oil (Liu et al. 2017). This finding indicates that the amount of food waste is sufficient when the collection and transportation scope are reduced. While strengthening regulations for food waste treatment, the government should strengthen controls on the unreasonable collection scope and increase the charges for long-distance collection and transportation from catering companies. In China, catering companies are able to sign collection contracts with food waste collection and transportation companies, but the government can set the price range for food waste collection and transportation. The practice of increasing long-distance freight is achievable. This approach can help the food waste disposal plant reduce the cost of collection and transportation.

The economic benefits of the food waste anaerobic treatment project mainly originate from the government subsidies. When the government subsidies are adjusted, this change will greatly impact the income of the food waste treatment industry. At present, a few food waste disposal plants misrepresent the amount of food waste disposal, defrauding government subsidy programmes and increasing profits (Wu 2015). According to an analysis of the development trends of the waste treatment industry on the Beijing solid waste website, the government has the willingness to regulate the subsidies for food waste disposal, and the food waste treatment plants face a potential risk of subsidy reductions. If the classification of food waste is improved and the scope of collection and transportation is rationally planned, the operating costs of food waste treatment companies can significantly decrease. And, the ability of food waste plant to adapt the subsidy adjustments can improve. In response to possible subsidy adjustments, the food waste treatment companies should accelerate their own development and reduce dependence on government subsidies. For example, these companies can develop new technologies and improve biogas production efficiency.

Conclusions

This paper focused on food waste treatment and analysed the input and output of collection and transportation, disposal, and resource utilization processes. This paper simultaneously analysed the environmental effects and economic benefits, which outweighed the previous shortcomings that only focused on economics and waste disposal. The field research method was used to obtain the research data. With the life cycle assessment method, the whole processes of food waste treatment were analysed. In the whole anaerobic treatment, 200 t of food waste can produce benefits of 66,888 CNY, and generate electricity energy 43,350 kW·h, which equivalent to reduce CO_2 emissions 16,087 kg. Although the food waste treatment economic and environment benefits are considerable, there still are some problems and potential risks in the food waste treatment industry. Generally, food waste treatment has achieved certain developments in China, but there are still the problems of waste sorting, the scope of waste collection, and transportation and dependence on government subsidies. The government should promote food waste classification and strengthen the supervision of food waste disposal in catering companies, providing a solid foundation for food waste treatment. Waste recycling is an inevitable trend of green and sustainable development. The waste treatment industry is facing a development opportunity and is worthy of intensive study.

Funding information Project supported by the Social Science Foundation of Beijing (16YJC062) and the Fundamental Research Funds for the Central Universities of China (2017MS082 and 2018ZD14).

References

Ahamed A, Yin K, Ng BJH, Ren F, Chang VWC, Wang JY (2016) Life cycle assessment of the present and proposed food waste management technologies from environmental and economic impact perspectives. J Clean Prod 131:607–614

Arafat HA, Jijakli K, Ahsan A (2015) Environmental performance and energy recovery potential of five processes for municipal solid waste treatment. J Clean Prod 105:233–240

Chen Y (2016) A cost analysis of food waste composting in Taiwan. Sustainability 8:1210

Clercq DD, Wen Z, Fan F et al (2016) Biomethane production potential from restaurant food waste in megacities and project level-bottlenecks: a case study in Beijing. Renew Sust Energ Rev 59:1676–1685

Clercq DD, Wen Z, Caicedo L et al (2017a) Application of DEA and statistical inference to model the determinants of biomethane production efficiency: a case study in South China. Appl Energy 205:1231–1243

Clercq DD, Wen Z, Lu X et al (2017b) Determinants of efficiency in an industrial-scale anaerobic digestion food waste-to-biogas project in an Asian megacity based on data envelopment analysis and exploratory multivariate statistics. J Clean Prod 168:983–996

Clercq DD, Wen Z, Fan F (2017c) Performance evaluation of restaurant food waste and biowaste to biogas pilot projects in China and implications for national policy. J Environ Manag 189:115–124

Du X, Chen T, Li H, Ren L, Jin Y (2010) Environmental impact analysis of two typical restaurant garbage regeneration technologies. Chin J Environ Eng 4(1):189–194 (in Chinese)

Eriksson M, Strid I, Hansson PA (2015) Carbon footprint of food waste management options in the waste hierarchy—a swedish case study. J Clean Prod 93:115–125

Hao X, Zhou P, Cao D (2017) Analyses of disposal methods and carbon emissions of food wastes. Chin J Environ Eng 02:673–682 (in Chinese)

Jiang J, Liao L, Bi Z (2012) Cost-benefit analysis of domestic waste classification in Shenzhen City. Environ Sanit Eng 01:20–23 (in Chinese)

Laurentiis D, Valeria H et al (2016) Overcoming food security challenges within an energy/water/food nexus (EWFN) approach. Sustainability 8:95

Li X, Tong J, Zhang C et al (2013) Research on food waste treatment planning: considering the diet culture of Chongqing. China Popul Resour Environ S2:416–420 (in Chinese)

Liao C, Hong J, Zhao D et al (2018) Confucian culture as determinants of consumers' food leftover generation: evidence from Chengdu, China. Environ Sci Pollut Res 25:1–15

Liu Y (2014) Supply chain logistics optimization research of restaurant kitchen waste—G company in Beijing. Dissertation, Capital University of Economics and Business. (in Chinese)

Liu B, He Y, Liu S et al (2016) Economic evaluation on a treatment project of kitchen waste. Environ Sanit Eng 01:36–37 (in Chinese)

Liu T, Wu Y, Xie H (2017) Status and countermeasures for food waste recycling management in Beijing. Environ Sanit Eng 01:83–84 (in Chinese)

Lo IM, Woon S (2016) Food waste collection and recycling for value-added products: potential applications and challenges in Hong Kong. Environ Sci Pollut Res 23:7081–7091

Meng QX, Huang T (2010) Quadratic exponential smoothing forecast of Chendu food waste production. Sichuan Environ 04:29–30 (in Chinese)

Miah JH, Koh SCL, Stone D (2017) A hybridised framework combining integrated methods for environmental life cycle assessment and life cycle costing. J Clean Prod 168:846–866

Oldfield TL, White E, Holden NM (2016) An environmental analysis of options for utilising wasted food and food residue. J Environ Manag 183:826–835

Opatokun SA, Lopez-Sabiron AM, Ferreira G, Strezov V (2017) Life cycle analysis of energy production from food waste through anaerobic digestion, pyrolysis and integrated energy system. Sustainability 9:1804

Reutter B, Lant P, Reynolds C, Lane J (2017) Food waste consequences: environmentally extended input-output as a framework for analysis. J Clean Prod 153:506–514

Secondi L, Principato L, Laureti T (2015) Household food waste behaviour in eu-27 countries: a multilevel analysis. Food Policy 56:25–40

Shahabadi MB, Yerushalmi L, Haghighat F (2010) Estimation of greenhouse gas generation in wastewater treatment plants—model development and application. Chemosphere 78(9):1085–1092

Shang L, Du M, Jing C et al (2013) Multisectoral collaborative kitchen waste management based on GIS and IOT. Internet Thing Technol 05:73–75 (in Chinese)

Song G, Li M, Semakula FK et al (2015a) Food consumption and waste and the embedded carbon, water and ecological footprints of households in China. Sci Total Environ 529:191–197

Song G, Du Q, Ma B (2015b) Social cost accounting for solid waste landfill disposal in Beijing. J Arid Land Resour Environ 08:57–63 (in Chinese)

Tan ST, Ho WS, Hashim H, Lee CT, Taib MR, Ho CS (2015a) Energy, economic and environmental (3E) analysis of waste-to-energy (WTE) strategies for municipal solid waste (MSW) management in Malaysia. Energy Convers Manag 102:111–120

Tan X, Shi L, Ma Z et al (2015b) Institutional analysis of sewage treatment charge based on operating cost of sewage treatment plant—an empirical research of 227samples in China. China Environ Sci 35: 3833–3840 (in Chinese)

Thyberg KL, Tonjes DJ (2016) Drivers of food waste and their implications for sustainable policy development. Resour Conserv Recycl 106:110–123

Veeramani A, Dias GM, Kirkpatrick SI (2017) Carbon footprint of dietary patterns in Ontario, Canada: a case study based on actual food consumption. J Clean Prod 162:1398–1406

Wang P, Ren L, Gan X (2013) Investigation and output factors analysis of restaurant garbage for cities in China. Environ Sci Technol 03:181–185

Wen Z, Wang Y, Clercq DD (2016) What is the true value of food waste? A case study of technology integration in urban food waste treatment in Suzhou City, China. J Clean Prod 118:88–96

Wu H (2015) Study on the construction of recycling logistics system. Dissertation, Shijiazhuang Tiedao university. (in Chinese)

Xiao Y (2015) The research of intelligent transportation route dynamic generation method based on temporal and spatial distribution of kitchen waste. Dissertation, China University of mining and technology. (in Chinese)

Xu X, Lan Y (2016) A comparative study on carbon footprints between plant- and animal-based foods in China. J Clean Prod 112:2581–2592

Zhang J (2018) Ways and efficiency analysis of landfill gas utilization in Beijing Liulitun landfill. Environ Sanit Eng 03:26–28 (in Chinese)

Zhang Y, Gao D, Chen T et al (2006) Economical evaluation of different techniques to treatment and dispose sewage sludge in Beijing. Ecol Environ 02:234–238 (in Chinese)

Zhang C, Wang X, Chen F et al (2012) Application research on the anaerobic digestion treatment technique of the kitchen waste in Beijing. Technol Dev Enterp 10:81–82 (in Chinese)

Zhang D, Cheng S, Gao L et al (2016) The carbon footprint of catering industry food waste: a Beijing case study. Acta Ecol Sin 18:5937–5948 (in Chinese)