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An Environmental and Economic Performance Comparison of the Food Waste Vacuum Collection and Kerbside Collection System with Anaerobic Digestion as the Final Treatment

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Abstract

A kerbside collection has been ubiquitous in some of the developed countries as a mean of food waste collection from sources to a food waste recycling facility such as an anaerobic digestion plant. As an alternative, a novel system named vacuum collection appears with its potential of cutting the waste collection frequency which in turn, reducing waste management costs. In this particular study, the environment and economic performance between prevailing kerbside collection system and hypothetical alternative using vacuum collection system were identified and compared. For the latter system, both of environment and economic assessment were determined based on the existing model at one of the colleges in London, in which the data were adjusted to the condition on a dense commercial and domestic area. The results of the comparative study showed that the use of vacuum collection system would result in 50% more net energy compared to another system. This is primarily due to less greenhouse gas emissions released and greater potential of biogas yield from the food waste contained in the system. In addition, the level of air pollution caused by waste transportation activities would be reduced due to less total vehicle distance travelled. Furthermore, the food waste vacuum collection system could also reduce the associated environmental cost by a half compared to the prevailing kerbside system.

Keywords: anaerobic digestion; biogas; food waste; kerbside collection; vacuum collection.

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1. Introduction

Municipal solid waste (MSW) is a potential source for future energy production, given that the daily generation rate is not season-dependent and the quantity produced is proportionally correlated with the rapid rate of population growth. Utilizing MSW as an alternative energy source to substitute fossil fuel through a biological treatment offers a wide range of benefits; not only fostering the implementation of a proper solid waste management in the municipality, but also providing measures to reduce greenhouse gas (GHG) emissions from landfill. Anaerobic digestion (AD) has become a matter of interest as a viable technology to treat organic fraction from MSW including food waste and at the same time to produce renewable energy. It has demonstrated its capability to maximize the use of the remaining value from organic waste material to yield two highly valuable products; a biogas mainly comprises methane and carbon dioxide and also a nutrient-rich stabilized liquid fertilizer for agricultural use. London is the most populous city in the UK with 7.75 million inhabitants in 2010 and accounts for 12.5% of the UK population [1]. In London, approximately 3,822,000 tonnes of MSW is generated daily, with organics (food and garden waste) and papers as the largest component of the MSW which; amounted to 32% and 23%, respectively [2]. Based on the Waste & Resource Action Program (WRAP) report, households and commercial establishments contribute more to food waste generation than industrial sources [3]. Therefore, these sectors are a prospective target with respect to renewable energy production through anaerobic digestion of food waste. To date, the management of food waste in London relies on conventional collection and disposal activities, known as the kerbside collection system. In this particular system, the local authority that responsible in solid waste handling, regularly collects food waste container located by the road side (kerbside) and then transports it to recycling facilities for food waste, such as composting or AD plants. The introduction of food waste vacuum collection system in the UK market presents strong potential to maximize the net energy produced by AD. In general, the vacuum collection system collects waste pneumatically and transfers it through tubes that connect several feeding inlets to a big container for further process. This system can therefore reduce the reliance on fossil fuels that required for waste transportation activities. Furthermore, this new system also considered as providing economic advantage by reducing waste collection costs, in which the said costs are accounted for 50-75% of the total MSW management costs [5]. Vacuum collection system used in this study differs from the underground type of vacuum collection system that has been studied by several authors [5, 6, 7]. The underground type typically serves large densely populated areas and could be utilized to collect a large variety of solid waste. This system has, however, a main drawback which is the development of underground infrastructures as it would require high capital costs and may create inconvenience to surrounding communities and business premises during the construction phase [6]. Therefore, the technology used here is a simpler form of vacuum collection technology without putting aside its potential for reducing vehicular movement for waste transportation. This type of vacuum collection system comprises several components, which are hopper, macerator, vacuum system, and hermetically sealed storage tanks. In the market, this system is available in wide range capacity from 1,500 liters to 10,000 liters. This implementation of vacuum collection system is deemed as will reduce the collection frequency of food waste to once in every 21-42 days without creating nuisance such as odor and vermin attraction [8]. Furthermore, this technology offers flexibility in installation whether it will be fully integrated with the buildings or containerized and placed outdoors where internal space is limited. Figure 1 depicts the outdoor containerized vacuum collection system where the vacuum unit is not integrated with the existing building.

(i) **(ii)** **(iii)**

Figure 1: The model of food waste containerized vacuum collection system at one of the universities in the UK that receive food waste from all the kitchens and canteen. The hopper as the feeding inlet for food waste (i), from the hopper food waste is transferred through pipelines by vacuum suction to the macerator (ii) and settle in the sealed storage tank inside the container (iii).

An analysis on the environmental and economic performance of the implementation of the food waste vacuum collection system as the best to the author's knowledge has not been conducted so far. This study thus, aims at filling in the knowledge gap for the use of vacuum collection units as an alternative in the food waste management system by looking at the model that has been operationalized at one of the colleges in the UK for more than 3 years. Therefore, this study will focus on assessing and comparing the environmental and economic performance of food waste vacuum collection system against the current kerbside collection system, with geographical focus in Greater London Area.

2. Research Methods

Herein the data to compare environmental and economic perspectives of the food waste vacuum collection system and kerbside collection system are described. Since kerbside collection is prevalent system in the case study area, empirical data is available for this particular system. In contrast, for the food waste vacuum collection system, the study undertaken was a hypothetical study with data provided by the system's supplier and model that is generated to suit the character of the study area.

2.1. Boundaries and Methods of Environment Analysis

For this study, the boundaries for assessment of the two systems were set to include the activities that are linked to the operation of either food waste collection system or prevailing kerbside collection system with AD as the final treatment. With regards to the environmental point of view, a quantification of GHG emissions and the identification of the food waste management's impact on air quality were performed. With respect to the latter, this study focuses only on the air pollutants caused by waste transportation activities, without considering air pollution from electricity production in the power plant that being used for food waste handling and treatment activities or the pollutants emitted by vehicles that deliver liquid fertilizer from the AD plant to nearby agricultural land. All primary pollutants including carbon monoxide (CO), nitrous oxide (NO_x), sulphur dioxide (SO_2), particulate matter (PM), volatile organic compound (VOC), and nitrogen dioxide (N_2O) were considered. To determine the amount of primary pollutants, emission factors according to the National Atmosphere Emissions Inventory (NAEI) were adopted [4]. The effect of climate change as a result from excessive release of GHG emissions is more global. Consequently, the coverage of the GHG accounting here was grouped in terms of direct emissions and indirect emissions. In this context, direct emissions refer to the emissions that are directly linked to the food waste handling and treatment activities, such as from waste transportation activities. Indirect emissions, on the other hand, are all emissions originated from relevant upstream or downstream activities of the waste handling and treatment activities other than waste handling and treatment activities themselves. The indirect emissions can be further divided into two main categories, the first one is avoided emissions arising from biogas recovered in the AD plant that can be utilized to offset energy production. Secondly are emission associated to the production of electricity in the power plant, which is subsequently used for the waste handling and treatment purposes and the emissions from the extraction and production of metals that is used in the manufacturing of the system components such as waste trucks, waste containers, and vacuum collection units. The GHG emissions were determined using emission factors that associated with the amount of an emitted pollutant to a unit of activity. Furthermore, in the GHG accounting, because this is a comparative study, the similar effect from the same type of activities in both systems were not accounted as they would eliminate each other and not affect the comparison results. Fugitive emissions from the AD plant and emissions associated with soil application of liquid fertilizer that is generated from AD process are two of the examples.

2.2. Boundaries and Methods of Economic Analysis

Two tools were employed for the purpose of economic performance evaluation in this particular study. The first tool is payback period estimation; a common method to determine whether the use of food waste vacuum collection unit in the case study area is considered as a worthwhile investment. The second tool is social life cycle costs (SLCC), in which the tool is used as a response to the European Commission's requirement to provide economic information as an addition to the environmental aspect assessment as part of decision making process on waste management [10]. The approach used in this tool involves both capital and operational costs as well as environmental impacts expressed in monetary units. The said approach is translated into the following Equation 1 [5].

$$SC = IC + OC + EC \qquad (1)$$

where IC is investment costs, OC is operational costs, and EC is environmental costs. In defining the capital and operating costs, a common calculation using annuity formula and discount rate was employed [5]. The discount factor is determined by using Equation 2.

$$Dn = \frac{1}{(1+r)^n} \qquad (2)$$

where Dn is the discount factor, r is the discount rate, and n is year-n. To estimate the life of the invested equipment, based on the interview with the supplier's system, the value of 15 years for the equipment's lifetime is deemed reasonable [6]. A value of 3.5% was used as a discount rate, as it is the recommended number for the UK public service discount rate [7]. Environmental costs encompass all environmental and social impacts to the surrounding community that caused by food waste management activities; such impacts are emissions, noise, odor, traffic, etc. In this study, only environmental impacts were quantified. Due to limited availability of value estimates for several impacts, then this study only emphasized on $CO_{2\text{-eq}}$, SO_2, and NO_x emissions. According to Teerioja and his colleagues [5], the value estimates for a tonne of $CO_{2\text{-eq}}$, SO_2, and NO_x are £18.68, £875.3, and £812.13, respectively.

2.3. Case Study Area and Food Waste Quantity for System Comparison

Throughout the study, the case study area used is not based on a real condition, but it was a scenario created based on assumptions, which was located in a selected area in the central London. The case study area was assumed to be an area of a dense commercial and domestic setting that comprises a hospital, a college, a hotel, a restaurant, and a high-rise building/apartment. In this current study, the amount of food waste from commercial operations, except for that from the college, was estimated based on proxy data. The sector-specific grossing up factors was then applied, according to the assumption made for size and type of commercial sectors. The food waste generation rate from the college was based on secondary data obtained from the interview with the waste recycling manager in one of the colleges in London, which is approximately 3 tonnes week^{-1} [8]. Utilizing the grossing up factors and secondary data, the total food waste generated in the study area is calculated as reaches approximately 250 tonnes year^{-1}. The size of the commercial operations and the amount of produced food waste are described in Table 1.

Table 1: Site specific data of sector grossing up factors and food waste generation rate

FW* source category	Sector grossing up factors (tonne FW year $^{-1}$)	Quantity of FW		Notes
		kg day^{-1}	tonne year^{-1}	
Hospital	0.28[a]	78.58	28.68	100 beds
Hotel	6.31[b]	44.85	16.37	Size band: number of employees 50-99
Restaurant	7.44[c]	58.36	21.30	Size band: number of employees 10-19
Apartment	270.00[c]	73.97	27.00	100 households
College	n.a	600.00[d]	156.00	6000-7000 staffs

FW: food waste

[a] per bed per year [9] ,[b] per site per year [9], [c] per household per year [10], [d] based on primary data [8]

2.4. Description of Food Waste Management Systems

2.4.1. Kerbside Collection System with AD plant as a final treatment

This scenario represents the prevailing food waste management in the case study area. Food waste is separated at source and stored in the specific-colored food waste containers that are located by the roadside at the front of each premises.

On a given specific schedule, the local authority responsible for waste collection loads the waste to the truck and transports it to a nearest AD plant which is located 25 miles away from the case study area. The waste collection trucks used in this study are two common heavy duty trucks with a capacity of 1-2 tonnes that used to collect MSW. The frequency of food waste collection from commercial establishments and domestic sectors are different depending on the business type. The food waste collection is undertaken on a biweekly basis for all commercial sectors, apart from food waste from college that are collected three times a week and from high-rise building that are collected twice a week [8]. The biogas yielded from the operation of AD plant is then valorized by the combined heat and power (CHP) engine with an electrical efficiency of 30% to produce electricity and heat simultaneously.

2.4.2. Vacuum Collection System with AD plant as a final treatment

This scenario involves the use of the food waste vacuum collection system that is fully integrated in the main kitchen in each of the buildings apart from those located in apartment.

This means the kitchen staff in all business premises could directly dispose of the unavoidable food waste at the stage of meals preparation such as shells, skin, and bones to the hopper of vacuum unit. Also, any leftover foods from the canteen at the college, from bedrooms in the hospitals as well as from restaurants could be disposed right away to the hopper of the vacuum collection system. In the apartment, however, the food waste vacuum collection system is built outdoors and containerized.

This way, the occupants bring their separated food waste to their apartment’s backyard where the vacuum collection is located. There would be one hopper or feeding inlets in each source, amounting to a total of five hoppers in five units of food waste vacuum collection system.

The size of the vacuum collection unit used at the college is 10,000 liters, while the remaining sectors use the 1,500 liters one. The selected capacity is determined based on food waste quantity. The output from the vacuum collection unit is food waste slurry that is emptied and picked up by tanker truck and transported to an AD plant. The same location of the AD plant with the previous system is applied.

3. Results and Discussion

3.1. Biogas Yield

Corresponding with GHG emissions in the AD process, biogas yield has a large impact on the net energy balance. Based on the report from one of the AD plant in London, the value of biogas yield from food waste slurry as outputs from vacuum collection system is higher than those yielded from typical food waste feedstock obtained from the literatures (Table 2).

Table 2: Biogas yield from the literatures

Biogas yield (m^3 $tonne^{-1}$ food waste)	Source
120.26	Long-sheng, and his colleagues [13]
86.12	Chu, and his colleagues [14]
111.44	Murto, and his colleagues [15]
125.16	Browne, and his colleagues [16]
108.6, 117.11	Hansen, and his colleagues [17]
135.57	Davidsson [18]
173.26	Gunaseelan [19]

This is primarily due to the condition of the hermetically sealed tank that reduce the potential for biogas loss from food waste during the storage. The absence of oxygen in the sealed tank enables the chemical nature of food waste such as heat value to be conserved. Conversely, in the kerbside collection, food waste generated is not directly processed or contained in the air-tight container. This way, food waste in the container would be exposed to the open air for a long duration, at the minimum of one day, but in actual, it is more likely that food waste would settle longer in the container. This condition allows the alteration of food waste properties, in which it may already have begun to break down, leading to potential biogas reduction [11]. The average of biogas yield from food waste slurry that is taken after 7 days storage from vacuum collection system is 207 m^3 biogas $tonne^{-1}$ [12], whilst average biogas yield from typical food waste based on the literatures is approximately 128.3 m^3 biogas $tonne^{-1}$ food waste.

3.2. GHG Emissions

3.2.1. Direct GHG Emissions

In terms of direct GHG emissions, the difference between the two systems appears from GHG yielded from waste transportation-related activities. The approach used to determine the GHG emissions from food waste collection and transportation is to use the typical GHG emissions from diesel-fueled trucks that has been reported in the Guidelines to DEFRA/DECC's GHG Conversion Factor for Company Reporting which is 0.51875 kg $CO_{2\text{-}eq}$ km^{-1} [20]. As expected, the use of the vacuum collection system in the case study enables the reduction of waste collection frequency which initially at least three times a week to once every 17 days as shown in Table 3.

Table 3: Emptying period of food waste slurry from vacuum collection system

FW generation source	Storage tank capacity (liter)	FW quantity (liter day^{-1})*	Emptying frequency (days)
Hospital	1,500	44	19
Hotel	1,500	77	34
Restaurant	1,500	72	26
Apartment	1,500	57	21
College	10,000	584.8	17

- The mass density value adopted for food waste slurry is 1026 kg m^{-3} [21].

Due to the variation in the emptying frequency of storage tanks, 17 days was selected as the suitable value. The maximum capacity of the food waste vacuum collection unit available in the market is 10,000 liters, hence, the emptying frequency for food waste from college could not be longer than 17 days. The food waste slurry from other sources (except for those from the hotel) then would be picked up by the 15,000 liters tanker truck following the emptying schedule of the vacuum collection system at the college, even though the food waste slurry volume in the other sources has not reached the storage tank's capacity during the emptying schedule. In the following emptying period, the food waste slurry from the hotel would also be picked up.

3.2.2. Indirect GHG Emissions

In an AD plant, the homogenized and reduced particle size of food waste slurry from vacuum collection unit allows this feedstock to be directly pumped into the digester, without the need for having further treatment as is needed by feedstock from conventional kerbside collection [15]. This means that the use of vacuum collection system in the food waste generation point would eliminate energy used in the pre-treatment stage within the AD plant. The operation of vacuum collection system, however, still requires electricity, even though it is fairly low, considering that electricity is only needed when the hopper has been fully filled with food waste and it is ready to be transferred to the hermetically sealed tank. Based on the model, the annual operation requires 500-kilowatt hour, and this value is taken as an annual electricity consumption for food waste vacuum collection system for each source. The reason is, despite the weekly operation of the vacuum collection system differs between the college and the other sources -where at the college it operates 5 days a week following the college schedule, while in other sources it operates 7 days a week- the quantity of waste produced at the college is much greater than the others, which subsequently the vacuum collection system would be operated more frequent leading to more electricity used. Hence, the assumed annual electricity consumption of 500 kWh for each source is acceptable. The same approach in estimating GHG estimation from waste transportation was used to estimate the GHG emissions from electricity. A value of 0.4939 kg $CO_{2\text{-eq}}$ kWh^{-1} is used as an emission factor for the electricity usage [20].

The manufacture of trucks, machinery and waste containers would involve other natural resources exploitation, hence the emissions from the manufacturing process should also be taken into account. The GHG estimates for the vacuum collection system is derived using emissions factor based on the Guidelines to DEFRA/DECC's GHG Conversion Factor for Company Reporting which is 4768.9 kg $CO_{2\text{-eq}}$ ton^{-1} used metal [20], as the equipment is predominantly made from metal. The weight of the vacuum collection unit is assumed to be able to represent the quantity of metal used. Likewise, due to the needs of tanker truck to periodically emptying the storage tanks, the natural resources used in the trucks manufacturing process was also included. By assuming that one unit of tanker truck and 2 different sizes of vacuum collection units are needed for the case study area~~,~~ this amounts to a total of 129,714 kg $CO_{2\text{-eq}}$ released as indirect emissions yielded from the manufacture of vehicle and machineries.

On the other hand, waste containers are generally made from high density polyethylene (HDPE) plastics. The GHG estimation in the manufacturing of waste containers was derived from the emissions factor for HDPE plastic production which is 3,194 kg $CO_{2\text{-eq}}$ $tonne^{-1}$ HDPE plastics used [20]. Given that the weight of 240-liter waste container is 13.5 kg per unit, thus 1,638.5 kg $CO_{2\text{-eq}}$ is released from container production process. Estimation of GHG emissions from the production of waste collection trucks used the same approach as for the tanker truck, by assuming the weight of the used trucks is 7.5 tonne per unit [22]. Table 4 describes the detail information of both direct and indirect emissions from two different systems.

Table 4: Direct and indirect GHG emissions from kerbside collection and vacuum collection system

Kerbside collection system		Vacuum collection system	
Direct emissions:	kg $CO_{2\text{-eq}}$ $year^{-1}$	**Direct emissions:**	kg $CO_{2\text{-eq}}$ $year^{-1}$
Fuel combustion in collection & transport activities	131.13	Fuel combustion in collection & transport activities	709.88
Indirect emissions:		**Indirect emissions:**	
Provision of electricity	2,389.2 kg $CO_{2\text{-eq}}$ $year^{-1}$	Provision of electricity	1234.75 kg $CO_{2\text{-eq}}$ $year^{-1}$
Manufacture of waste containers	1,638.52 kg $CO_{2\text{-eq}}$	Manufacture of vacuum collection unit	29,567.2 kg $CO_{2\text{-eq}}$
Manufacture of waste trucks	71,533.5 kg $CO_{2\text{-eq}}$	Manufacture of tanker truck	100,146.9 kg $CO_{2\text{-eq}}$

Another difference also comes from the avoided emissions as the biogas produced can replace the extensive use of energy to generate electricity. Due to higher potential biogas yielded from contained food waste in the vacuum collection system than those from typical food waste feedstock, the energy production from an AD plant that possesses vacuum collection system as its pre-processing step would be greater than that without.

Nevertheless, the biogas yields that was referred in the vacuum collection system scenario were the values from food waste samples taken after 7 days storage. As the food waste emptying period from hermetically sealed tank was assumed to every 17 days, it is more likely the biogas yield would be smaller, which was not considered here due to limited information on the effect of storage duration to the food waste potential biogas yield.

Here, to determine the electricity generation rate, the CHP engine efficiency, methane volume in biogas and the high heating value of methane are considered. It is obtained that the electricity generation rate corresponding to the biogas yield from the output of vacuum collection system and typical food waste are 132,425 kWh year^{-1} and 66,493 kWh year^{-1}, respectively. The net energy as a result from the deduction of the total emissions released with the avoided emissions is reflected in Figure 2.

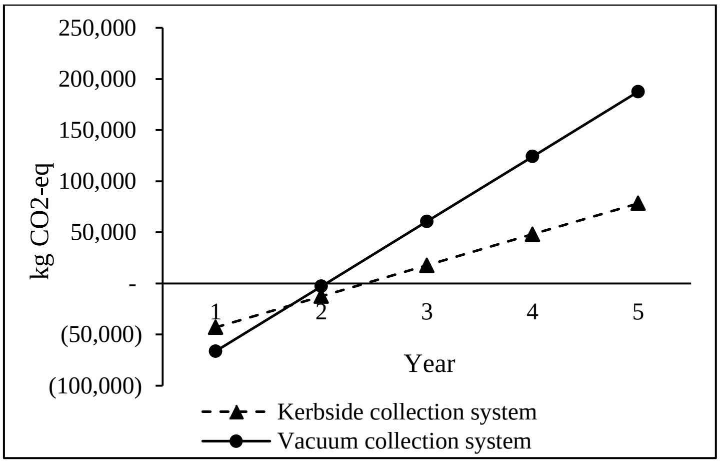

Figure 2: The net energy from kerbside collection and vacuum collection system

The results reveal that in the first year when the investment costs are allocated, the net energy from AD plant as a subsequent process from either the vacuum collection or kerbside collection system is negative. This indicates that the CO_2 equivalent emitted by the process is greater than avoided emissions, which deriving from renewable energy production of anaerobic digestion process. This is due to high indirect emissions associated with the manufacturing process of the machinery and vehicles itself. At the same time, the vacuum collection method exhibits greater GHG emissions than another system, mainly due to more resources are used in the manufacture of the vehicles and machineries. With regards to the biogas generated, the vacuum collection system possesses higher net energy with a total of +261.6 $CO_{2\text{-eq}}$ per tonne waste, compared with the net energy of +126 $CO_{2\text{-eq}}$ per tonne waste for the kerbside collection, both are applied with AD as the final treatment.

3.3. Air Emission

The accounted primary pollutants here are those originated only from food waste collection and transport activities. Figure 3 presents the pollutants emitted per ton of collected food waste prior and after the use of vacuum collection system in the case study area. The results reveal that due to the distance travelled is reduced by 8 times in the vacuum collection method than in the current system, then there is approximately 86% decline on the emission of primary pollutants for air pollution.

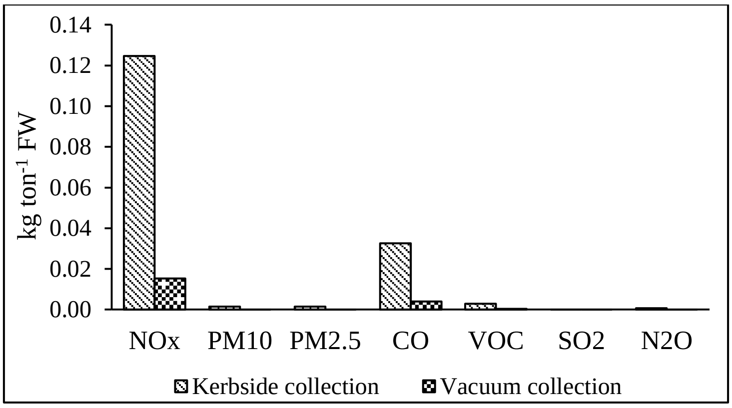

Figure 3: The comparison of primary pollutants resulted from two systems

3.4. Economic Performances

3.4.1. Capital and Operating Expenditures

Capital expenditures are described as the capital sum needed to supply the necessary manufacturing and plant facilities. The kerbside collection method invests in two units of waste trucks to be used interchangeably and 240-liters containers for food waste prior to collection and further treatment. Meanwhile another scenario involved the installation of complex high-grade machinery and thus, related cost implications.

Operating expenditure is defined as the total costs of resources used by the organizations to maintain the existing operation of a facility. It is common practice that there would be a fee that should be paid by the local authority when the food waste is intended to be treated in the food waste recycling facilities like an AD plant, called a gate fee. In London, the gate fee for food waste treatment in an AD plant ranges between £35 to £60 tonne^{-1} food waste in 2008. However, based on an interview with one of the anaerobic digestion plant's manager in London [12], value of £35 is deemed reasonable to be used. In terms of collection and transport cost, the value generally differs according to the container size. Based on the benchmark study by WRAP [23], the average cost of food waste collection is £18 for a 240-liters container lift. Based on the calculation, the number of container needed in the college, hospital, apartment, hotel and restaurants corresponding to the food waste quantity generated in each source then are 20, 4, 8, 3, and 3, respectively. The accounted containers are only for containers that are allocated for source-separated food waste.

The operation of vacuum collection system does not require extra staff as food waste collection fits easily with the existing responsibilities of either kitchen staff or householders, hence, the costs associated with labor wage do not need to be taken into account. With respect to the gate fee, it is within reason that food waste slurry would costs lower than that of the unprocessed food waste from kerbside collection.

This is because the slurry has been in the form to be directly pumped into the digester and subsequently be digested without the need of further treatment. Based on secondary data obtained from an interview with one of the operation manager of anaerobic digestion plant in London, the processed food waste feedstock could be costed as low as £25 per tonne feedstock [15]. Table 5 presents the breakdown of capital costs as well as operating costs for vacuum collection system and kerbside collection.

Table 5: Capital and annual operating costs of kerbside collection and the vacuum collection system

FW management system	Capital costs in £	Annual operating costs in £
Kerbside collection – AD plant		
240 liters FW containers	2,084	-
2 units waste trucks	152,000[a]	-
Total collection cost	-	81,120
Total gate fee		9,974
Vacuum collection unit – AD plant		
Vacuum collection unit:		
College	78,000[b]	-
Hospital	55,200[b]	-
Apartment	55,200[b]	-
Hotel	55,200[b]	-
Restaurant	55,200[b]	-
Total collection cost	-	10,230[c]
Total gate fee	-	6,725
Total maintenance costs	-	15,000[d]

[a] Value based on www.parristrucksales.com [24]

[b] Investment cost based on the interview with the system’s supplier [6]

[c] Rent fee for 15,000 L tanker truck, with £465 for 1 trip [8]

[d] Maintenance costs appears in the second year after the purchase [6]

3.4.2. Economic Viability

By comparing capital costs with the savings arising from the displacement of collection and transport cost as well as from a lower gate fee, it is calculated that the payback period of investing in 5 units of food waste vacuum collection system in the case study area is 5 years. In this case, the payback period is less than the life of the project so the investment is acceptable.

Economic viability for the two food waste management systems can also be assessed by analyzing their SLCC. The result for SLCC analysis is given in Table 6, which presents the total social costs for two different systems of food waste management.

Table 6: Social cost for kerbside collection and vacuum collection system (in £ per tonne food waste)

	IC	OC	EC		Total costs
Kerbside collection	41.1	279.7	$CO_{2\text{-eq}}$	-2.27	318.7
			SO_2	<0.001	
			NO_x	0.101	
			Total	-2.16	
Vacuum collection	79.7	98.1	$CO_{2\text{-eq}}$	-4.74	173.07
			SO_2	<0.001	
			NO_x	0.01	
			Total	-4.73	

Calculation shows that the environmental costs for both systems are significantly low. It only contributes -0.62% and -2.73% of the total social costs arising from the prevailing kerbside collection and vacuum collection systems, in that order. The negative value indicates that more benefits are gained by the society than the associated costs. The benefits are arising from renewable energy production by AD process as a subsequent treatment, so it can offset the utilization of fossil fuel to produce electricity. The largest share of the social costs component in the kerbside collection is the operational costs, which contributes over 80%, in contrasts with its investment cost that is only 12.8%. On the other hand, the investment and operational costs of vacuum collection system constitute almost equally to its social costs which are 46% and 56%, respectively.

Comparison of OC from both methods shows quite different value, in which the OC for kerbside collection method is three times higher than those from vacuum collection method. The OC value for kerbside collection system is deemed as reasonable compared to the collection cost in others European countries which ranges from €45 to €302 per ton of food waste [25]. Even though the value can be as low as €45 per ton food waste, however, the value really depends on the collection frequency, in which it could be as rare as on a fortnightly basis compared to this study that has more frequent food waste collection. Furthermore, the treatment cost is excluded from that lowest cost, while the result from the economic analysis has encompassed the gate fee for treatment in the AD plant. Another factor that leads to higher food waste handling costs is due to the different approach taken when estimating operating costs that use the cost per container lifts rather than the cost per tonne waste collected. This is due to the capture rate of food waste in the case study area is quite small, leading to higher operational costs.

4. Conclusions

A kerbside collection with an AD as the subsequent treatment to generate biogas as a renewable energy has been a popular practice in the food waste management in London. The food waste vacuum collection method is then emerged as an alternative solution to reduce the environmental impacts caused by prevailing kerbside collection and most importantly to reduce the waste management costs. From environmental and economic point of view, those two different systems that take setting in a dense domestic and commercial environment in the central London were compared. The results of this comparative study suggested that the use of food waste vacuum collection system implies higher production of net energy than those produced from the prevailing kerbside collection system. Furthermore, as the distance travelled by the waste collection truck was reduced, the air pollution could also be reduced. With respect to the economic performance analysis, based on the payback period evaluation, the food waste vacuum collection system is deemed as a worthwhile investment. Moreover, according to the SLCC analysis, the vacuum collection system possesses total social costs that is a half than the kerbside collection method.

5. Recommendations

The insight of the present study can be enriched with the following recommendation for future work. Potential biogas yield has a significant impact on the net energy balance. It would be an interesting area of research to investigate the effect of food waste storage duration in the hermetically sealed container to the value of potential biogas yield.

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