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AN ENVIRONMENTAL AND ECONOMIC COMPARISON OF FRUIT AND VEGETABLE WASTE TREATMENT IN THE TRADITIONAL MARKETS

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ABSTRACT: Two different fruit and vegetable waste (FVW) collection and treatment systems have been evaluated and compared with the existing system in the largest traditional market located in Bandung city, Indonesia. In this study, greenhouse gas quantification was performed to compare the environmental impact of current landfill practices against two different options: (i) on-site composting, and (ii) on-site anaerobic digestion. In addition to this, the economic performance was also evaluated by estimating the cost-output ratio from cost-effectiveness analysis and the payback period. The evaluation results were then presented in the matrix of strength, weaknesses, opportunities, and threats (SWOT) to provide an insight for the decision maker in determining the most appropriate solution for fruit and vegetable waste treatment system in the traditional markets. The results indicated that the alteration of FVW management system from the landfill to an on-site composting would decrease the cost-output ratio by 20%. Meanwhile, the implementation of an on-site anaerobic digestion showed a negative value of cost-output ratio indicating a profitable system. Furthermore, the estimation on net energy balance revealed that one ton of waste treated in a landfill, composting and anaerobic digestion would result in 3.52, 0.01 and -0.12 ton $CO_{2\text{-eq}}$, with the negative sign indicating the energy production. In addition, the payback period for anaerobic digestion and composting are remarkably short; around 8 and 13 months, respectively. These two alternatives, however, would be less advantageous if the government cannot ensure the availability of target sectors that may benefit from the utilization of compost and digestate.

Keywords: Market waste, Fruit and vegetable waste, Greenhouse gas emissions, Cost-effectiveness analysis

1. INTRODUCTION

Bandung city is one of the biggest cities in Indonesia with a population of over 2 million, where the average waste generation rate is 0.6 kg capita^{-1} day^{-1}, resulting in approximately 1,500 – 1,600-ton waste disposed of in landfill each day [1]. With respect to the waste management system, Bandung city still highly depends on landfill. The landfill currently in use, namely Sarimukti, is located in the western part of Bandung. The life-span of the landfill was predicted to be reached within three years [2], rendering crucial the availability of alternative systems waste management in the city.

Waste from traditional markets in Bandung is the second largest source of municipal solid waste in the city [1]. Traditional markets in Bandung and most of the cities in Indonesia are very popular since they provide a huge variety of fresh food materials and offer cheaper prices than those offered in grocery stores. The largest share of the waste from traditional markets consists of organics, followed by plastics, paper and relatively small amount of glass, metal, textile, and wood. The organics predominantly consist of fruit and vegetable waste (FVW), constituting about 60-85 % of the total bulk waste [3]. The solid waste handling in the traditional market typically utilize a handcart or where the space between vendors is too narrow, the bamboo basket is normally used.

Considering that the majority of the waste is high in moisture and perishable, either composting or anaerobic digestion can be considered as an appropriate sustainable means of treatment for waste from traditional markets. The high generation rate of FVW has raised the issues in public's mind of not only how to reduce the amount of FVW disposal to landfill to extend the lifetime of the landfill, but also how to divert FVW from landfills to avoid higher rate of release of methane (CH_4), a much more potent greenhouse gas (GHG) than carbon dioxide (CO_2).

Traditional markets would receive benefit from the use of either composting or anaerobic digestion in terms of the reduction of environmental impacts, compared with the current practice. The benefits will be doubled if the on-site system (referring to technologies existing closely to the source) is applied. This is due to less waste collection costs and, simultaneously, fewer GHG emissions from collection and transportation activities.

To demonstrate the performance of waste management alternatives, the analysis of the environmental and economic aspects were performed. The quantification of GHG emissions is considered acceptable as one of the means to evaluate the environmental performance of the alternatives proposed in this paper. Additionally, to evaluate the economic performances, the payback period of the allocated investment in the proposed alternatives and the cost-output ratio were determined. The cost-output ratio as a result of cost-effectiveness analysis is a parameter commonly used to measure the effectiveness of two or more existing alternatives [4]. Furthermore, an inventory of GHG emissions to compare different on-site biological waste treatments within the scope of traditional markets has not been conducted so far, to the author's knowledge. Thus, this study also aims at filling in the knowledge gap to provide information on the amount of reduced GHG emissions when composting or anaerobic digestion is applied to shift FVW disposal away from landfill.

A decision to choose a particular system from amongst a set of alternatives commonly requires investigating the positive and negative aspects of the system. An approach to strength, weaknesses, opportunity, and threat (SWOT) analysis is used in this study to present the benefits, the drawbacks, the potential improvements and the challenge of alternative systems, as SWOT method has been used widely as a key tool to support decision-making process in solid waste management system [5, 6].

2. METHODS

2.1 Data collection

This paper emphasizes on the FVW produced from the traditional market in Bandung city. A survey of the biggest traditional market containing approximately 200 vendors, namely Gedebage, has been conducted to estimate the amount of generated waste and its composition. Waste sampling was performed in accordance with the Indonesian standard; Standard Nasional Indonesia (SNI) 19-3694-1994. The characterization of physical and chemical properties of the FVW samples was conducted in the Solid and Hazardous Waste Laboratory in Institut Teknologi Bandung. The interview with several relevant people such as the head of the market, staffs from local sanitation office, landfill practitioner, and relevant government institution's staff has also been undertaken to obtain site-specific data needed in this study.

2.2 Environmental and Economic Assessment Methods

Two alternative scenarios of on-site FVW treatment, which are composting and anaerobic digestion were developed and simulated to be implemented in the vicinity of the Gedebage market. As such, the assumptions made for each of the scenarios utilized specific data from the market. The environmental impacts and economic performance from the two alternative scenarios against the current landfill practice (baseline scenario) were then evaluated and compared by assuming that only FVW was processed.

To quantify GHG emissions from landfill, composting and anaerobic digestion, in this paper, the conversion and emissions factors for diesel fuel combustion were determined from Intergovernmental Panel on Climate Change [7], while others were estimated from existing literature as well as the guidelines from Department of Energy and Climate Change and Department for Environmental Food & Rural Affairs [8]. The general equation for emission estimation by using emission factor is as seen in Eq. (1) [8].

$$E = A \text{ x } EF \text{ x } (1 - ER/100) \quad (1)$$

where E is emissions, A is a unit activity (e.g., kilowatt-hour electricity used), EF is emission factor (e.g., kilograms of CO_2 per kilowatt-hour electricity used), and ER is emission reduction efficiency (%).

However, in particular cases, a different approach is used to determine GHG emissions in order to obtain more reasonable values. In this study, to estimate the number of GHG produced during anaerobic decomposition in a landfill, the Landfill Gas Emission Model (LandGEM) v3.02 was used in present study. LandGEM is an estimation tool that provides a relatively simple approach to quantifying landfill gas emissions based on a first-order decomposition rate equation [9]. The advantage of the LandGEM model is that both of CH_4 and CO_2 generation is being calculated. Nonetheless, several waste types cannot be modeled at the same time. The variables used are degradable organic carbon (DOC) and decay rate value (k) in a wet climate, with the values of 0.15-ton carbon in waste ton^{-1} waste and 0.19 year^{-1}, respectively [10]. All the input parameters were applied for MSW and obtained from the LandGEM software. CH_4 generation potential (Lo) was then calculated based on Eq. (2) [10].

$$Lo = 493 \text{ x } DOC \quad (2)$$

Among the two alternatives, only anaerobic digestion can provide revenues since it produces methane that is converted to electricity which then is used for the operation of both anaerobic digestion itself and daily market. This also means that the revenues can offset the bills that are used to be paid by the traditional market. The formula to estimate electricity generation from biogas conversion is shown in Eq. (3) [11].

$$\boldsymbol{Electricity} = \boldsymbol{biogas\ production\ x\ \%\ methane\ \ x\ HHV} \quad (3)$$

where, HHV = high heat value of methane, equal to 22 MJ/m^3 methane

In the economic assessment, the payback period is one of the determining factors in the decision making on whether to undertake the project, as longer payback periods are commonly undesirable for decision makers. In the cost-effectiveness analysis, the preferred alternative should have the least cost-output value. In this analysis, the net costs of a project and the outcomes were compared. Moreover, the calculation formulas also took the time value of money into consideration.

An annuity formula and discount factor were then used to define the capital and operating costs throughout the life of the invested equipment. Here, the project lifetime of 15 years was deemed reasonable. The discount rate of 4.5% [12] was used to calculate the discount factor that is expressed in the Eq. (4) [13].

$$\boldsymbol{Dn} = \frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{r})^{\boldsymbol{n}}} \tag{4}$$

where Dn is the discount factor, r is the discount rate, and n is year-n.

The results from GHG quantification and economic analysis would become the key factors that included in the SWOT analysis. The comparisons among factors would be conducted within every SWOT group and presented to provide information for the decision makers in determining the most appropriate solution to manage FVW from traditional markets.

3. RESULTS AND DISCUSSION

3.1 Waste Composition and Characteristics

Gedebage market lies in an area of 12 hectares, with the daily waste generation rate approximately 11 ton. Based on the observation and waste sampling in the Gedebage market, the FVW shares about 62% of the total waste generated, which amount to 7 ton day^{-1}. Apart from FVW, the market waste also comprises 18.7 % other organics, 13% plastics, 1.5% papers and 3.8 % inert materials. Table 1 shows the FVW characteristics.

Table 1. FVW characteristics

Site-specific data	Value	Site specific data	Value
Waste density (kg/m^3)	459.5	VS (%)	82.75
		N (g/kg TS)	16.6
Moisture (%)	66	P (g/kg TS)	3
C/N	26.5	K (g/kg TS)	12
TS (%)	13		

3.2 GHG Emissions from Landfill

This scenario was created based on the real practice in a typical landfill in Bandung city. The landfill is located in the outskirts of the city, 51 km away from the Gedebage market, and the waste is transported by a dump truck (with the capacity of approximately 10 m^3) to the landfill twice a day. In this study, based on the typical waste collection trucks in Indonesia, the diesel consumption value of 0.25-0.5 km $liter^{-1}$ was deemed acceptable [14]. Nevertheless, other variables, such as the number of vehicles operated in landfill scenario, were adjusted corresponding to the given value of daily FVW generated from the Gedebage market. Based on an interview with a staff in Sarimukti landfill site, to manage the solid waste from Bandung city, there are 5 bulldozers and 5 excavators that currently operate for 8 to 14 hours daily. Here, only a bulldozer and an excavator are used, of which diesel consumptions were 30 and 20 liters per hour for each [15]. Due to the fewer amount of waste disposed to the landfill scenario in the present study and considering that only FVW was taken into account, the daily operating hours of bulldozer and excavator were assumed to be shorter, at the rate of 5 hours per day.

The emissions associated with the combustion of diesel fuel for vehicles operation were estimated from IPCC, with the input data of emission factors for diesel fuel combustion and diesel properties. These values and several other conversion and emission factors obtained from the literature were repeatedly used in this study and given in Table 2.

Table 2. Typical values of GHG conversion factors

Activities	Conversion & Emissions Factor
Combustion of diesel oil[a]	72,000 kg CO_2/TJ (CO_2)
Diesel (100% mineral diesel)[a]	3.9 kg CH_4/TJ (CH_4)
Provision of diesel fuel[b]	0.502 kg $CO_{2\text{-eq}}$ $liter^{-1}$
Provision of electricity[c]	0.412 kg $CO_{2\text{-eq}}$ kWh^{-1}
Provision energy of fertilizer production[d]	
- Production of N fertilizer	8.9 kg $CO_{2\text{-eq}}$ kg^{-1} N
- Production of P fertilizer	1.8 kg $CO_{2\text{-eq}}$ kg^{-1} P
- Production of K fertilizer	0.96 kg $CO_{2\text{-eq}}$ kg^{-1} K

[a] [7]; [b] [16]; [c] [8]; [d] [17].

By using the relevant emissions factors in Table 2 plugged into Eq. (1), the GHG emissions resulted from the following activities: FVW transportation from the market to the landfill site and the daily operation of landfill vehicles, amount to 5,510 ton $CO_{2\text{-eq}}$ $year^{-1}$ and 185.76 ton $CO_{2\text{-eq}}$ $year^{-1}$, respectively.

With respect to the diesel fuel usage in landfill practice, the production of diesel fuel from crude oil also contributes to GHG emissions. According to the emission factor for provision of diesel fuel in Table 2, GHG emissions resulted from the production series of diesel fuel used in the waste transportation and the operational of landfill vehicles then are amounted to 1,067.2 and 36.5 ton $CO_{2\text{-eq}}$, respectively.

Based on the calculation of Eq. (2) and modeling in LandGEM, assuming that methane content is 50% by volume, given that 7 ton of FVW from the Gedebage market is disposed to landfill, it was obtained that CH_4 and CO_2 emissions from waste decomposition in a landfill within a year are 104.2 ton and 286 ton, respectively.

3.3 GHG Emissions from an On-Site Composting

The wastes from fruit and vegetable sections in the case study area are transferred to an on-site composting plant. To reduce the potential nuisance from FVW, in-vessel composting is used rather than windrow composting. The weekly plant operation is 48 hours and all the equipment use electricity as a power source. Pre-treatment utilizing shredding machine is applied to reduce the waste size prior to entering the composter. The in-vessel composter and its supporting equipment used in this study are of the types that have been commercialized and widely used in many different sectors in Bandung, which is the rotary drum composter. The total number of rotary drum composter needed is 25 units, given that the designed capacity is 2 ton for each unit, with the dimension of 0.3m x 0.208 m x 0.234 m [18].

The rotary drum composter is equipped with a motor that periodically rotates the drum composter. As the drum composter rotates, the waste inside would be reversed, which in turn, increase the air supply. Based on the supplier's claim, the aerobic decomposition would take 10 days to produce compost from FVW due to mixing system and the addition of starter microorganism that enable to accelerate the process [18] . This study also assumed that the compost would be in curing stage for 30 days before it can be mechanically sieved to obtain uniform size compost. The compost is delivered to the nearest local farmland in Pangalengan district, located 50 km away from the Gedebage market. Compost generated is provided for free rather than being traded for the farmers. In this scenario, based on the typical heavy trucks available in Indonesia, the diesel consumption value of 0.25-0.5 km liter^{-1} [14] was used.

In accordance with the specification of shredding, rotary drum composter and sieving machine [18], the daily electricity used is around 87-kilowatt hour (kWh). The consumption of electricity used by the machines is equal to 9.34 ton $CO_{2\text{-eq}}$ year^{-1}, corresponding to emission factor for electricity generation in Table 2**.**

Determination of CO_2 emissions from composting can be undertaken by two approaches, either by performing a carbon balance or using an appropriate emission factor for composting operation [10]. In this paper, the latter approach was used, using the default emissions factor for composting based on values from IPCC of 0.44 kg CO_2 kg^{-1} dry solids treated, of 0.004 kg CH_4 kg^{-1} of waste treated (wet basis), and of 0.0003 kg N_2O kg^{-1} of waste treated (wet basis). In accordance with the default emissions factor and the waste characteristics, the total $CO_{2\text{-eq}}$ emissions from composting are 15,000 ton year^{-1}. Several early studies neglected CH_4 emissions yielded from composting, despite the fact that CH_4 still presents in a very limited quantity [19]. The same approach towards methane emissions was applied in this paper. CO_2 emissions resulting from biological decomposition, termed biogenic CO_2, was not considered in total GHG emissions due to it being deemed as carbon neutral.

The GHG inventory associated with avoided emissions include the use of compost on land as a soil amendment. Such use contributes to reducing the GHGs emissions by removing the intensive use of resources in the production of commercial inorganic fertilizer. According to the N, P, and K content in Table 1, the nitrogen (N), phosphate (P) and potassium (K) content is 8 kg N ton^{-1} compost, 1.44 kg P ton^{-1} compost, and 5.77 kg K ton^{-1} compost, respectively, assuming that the dry matter content of compost is 48% [20]. This study assumed that all the nutrients from the compost were able to be taken up by plants. The avoided emissions from energy offset utilized by manufacturing to produce commercial fertilizer were estimated based on the compost produced, given that the FVW loss 50-70% of its mass during decomposition and the maturation stage [21]. Therefore, in one year, the compost produced would be approximately 1,533 ton with 12,200 kg N, 2,200 kg P, and 8,840 kg K available to be added to the soil. The use of compost to replace synthetic fertilizer was estimated to result in the avoided GHG emissions of equal to 207.3 ton $CO_{2\text{-eq}}$ year^{-1} (Table 2).

The GHG emissions associated with the compost distribution to agricultural land was relatively small. Considering that the compost is distributed 10 times a year and that the monthly consumption of diesel fuel by the truck used is 200 liter, the emissions were estimated to be 5.33 ton $CO_{2\text{-eq}}$ year^{-1}. Moreover, the provision of diesel fuel usage in compost distribution was calculated to lead to the annual emission of equal to 1 ton $CO_{2\text{-eq}}$.

3.4 GHG Emissions from an On-Site Anaerobic Digestion Plant

The scenario is analogous to the composting scenario. However, it differs in terms of the FVW being sent to an on-site dry anaerobic digestion plant. The anaerobic digester has a capacity of 7 tons FVW per day, with 30 days of retention time. These data along with several chemical properties of FVW in Table 1 enables the calculation of reactor volume which equal to 300 m^3, which the reactor radius is 3.5 m and height of 7 m (2 units). Similar to the former scenario, the weekly operation of anaerobic digestion plant is 48 hours. Pre-treatment is applied to reduce the waste size prior to entering the anaerobic digestion reactor. In the stage, before biogas is generated, the plant uses electricity from the grid for its operation, which will later be substituted by converted biogas after it is produced by the reactor. The anaerobic digestion plant normally utilizes, on average, 14% of the produced biogas to substitute the electricity used for its daily operation [22].

The amount of off-loaded digestate (the by-product of anaerobic digestion) is 80% of the FVW intake [23], which is up to 5.6 ton per day. The digestate is temporarily stored in a covered storage tank before it is delivered to agricultural land to substitute the purchase of synthetic fertilizers. The same distance to the nearest farmland and vehicle types for digestate transportation as described in the former scenario was applied for this scenario. Similar to the compost scenario, the generated digestate is provided for free rather than being traded for the farmers.

Fugitive emissions of methane may possibly escape from the digester, biogas storage, as well as from pipes and valves. It has been estimated that an average of 5% of the produced methane is lost to the atmosphere as fugitive emissions [17]. As the average value of methane potential from FVW was estimated to be 0,3 m^3 CH_4 kg^{-1} VS [24], the biogas generated was calculated to equal to 636,200 m^3 in one year.

During biogas conversion to energy and CO_2, it is possible that some methane is left. This is due to, in most cases, the inability to achieve complete biogas combustion, which leads to GHG emissions. With respect to the amount of unburned methane, the value of 15-24 kg $CO_{2\text{-eq}}$ ton^{-1} wet waste is adopted as suggested by Moller et al [17].

With respect to the digestate distribution to the local farmlands, based on the emission factor in Table 2, the diesel fuel combustion and the production series of fuel generated GHG emissions are equal to 6.4 and 1.2 ton $CO_{2\text{-eq}}$ $year^{-1}$, respectively.

The single largest avoided emission comes from converting methane to electricity, which can be utilized in the traditional market. To determine the amount of the produced electricity, the numbers for the efficiency of biogas engine and the methane content in biogas are required. In accordance with Eq. (3), 60% of methane content in biogas was assumed and the value of gas engine equal to 22% [11] was used, resulting in the electricity generation rate of approximately 878,713 kWh $year^{-1}$.

Avoided burdens from removing the intensive use of energy in producing inorganic fertilizers are estimated based on the amounts of nutrients contained in digestate that can substitute the nutrients in the organic fertilizer. As the nutrient losses in anaerobic digester are considered to be very small, it is assumed that nutrient content in the digestate is similar to those in FVW. Each of kilogram digestate then will comprise N, P, and K in the given order of 15.74, 2.45, and 6.49 g kg^{-1} digestate [20]. This amount of nutrient in the digestate resulting in the total avoided the burden of equal to 308 ton $CO_{2\text{-eq}}$ $year^{-1}$.

3.5 Comparison of Economic Analysis

Table 3 summarizes input data used to make concise cost estimates, which include both investment and operating costs, for the three FVW management methods. By using the value from Table 3 and discount factor obtained from Eq. (4), Figure 1 depicts capital and operating costs and the cost-output ratio from the two alternative scenarios and baseline scenario.

The cost comparison reveals that the construction costs in the composting scenario are three times higher than that in anaerobic digestion, mainly due to a larger area required for curing phase that implies more construction works. In comparison, the construction costs for landfill scenario is seven times more expensive than that for composting. Nonetheless, the composting and anaerobic digestion still require investments associated with the provision of heavy machines. Besides the construction cost, it is also observed that the operating costs are four and fifteen times higher in baseline scenario compared respectively to composting and anaerobic digestion scenarios. This huge cost difference is caused predominantly by transportation costs, operation costs of landfill vehicles, labor wage, leachate treatment cost etc. In comparison, the operating costs in other scenarios comprise mostly of labor wage and vehicle rent cost used for by-product distribution. Interestingly, the anaerobic digestion scenario has a negative value of the cost-output ratio, indicating that earnings generated exceeds the annual operating cost

In the composting scenario, the payback period was estimated by comparing capital costs with the savings arising from the displacement of collection and transport costs. In comparison, apart from the aforementioned displacement costs, the anaerobic digestion scenario also produces the benefit of electricity cost displacement. According to Ministry Regulation of Energy and Mineral Resources of the Republic of Indonesia, No 4 of 2012, the tariff for solid waste-based electricity is IDR 1,050 kWh^{-1}, hence the annual revenue gained in anaerobic digestion scenario amounted to IDR 830,383,785. It was calculated that the payback period from composting and anaerobic digestion scenarios are 13 and 8 months, respectively.

Table 3. Cost input data of two alternatives and baseline scenarios

Landfill	Value	Reference		Value	Reference
Investment costs:			*Operating costs:*		
• Construction costs (IDR/ton waste)	94,250	[25]	• Waste transportation costs (IDR/ton waste)	424,322	[1]
			• Landfill operational costs (IDR/ton waste)	81,000[a]	[25]
On-site composting	**Value**	**Reference**		**Value**	**Reference**
Investment costs:			*Operating costs:*		
• Building construction (IDR/m^2)	340,000	[26]	• Labor costs (IDR/person/day)	40,000	[27]
• 25 units of in-vessel composter (IDR/unit)	40,000,000[b]	[18]	• Electricity cost (IDR/kWh)	1,467	[28]
• 1 unit of shredding machine (IDR/unit)	15,000,000	[18]	• Truck rent cost for compost distribution (IDR/month)	22,000,000	[29]
• 1 unit of sieving machine (IDR/unit)	26,000,000	[18]			
On-site anaerobic digestion	**Value**	**Reference**		**Value**	**Reference**
Investment costs:			*Operating costs:*		
• Building construction (IDR/m^2)	453,000[b]	[26]	• Labor costs (IDR/person/day)	40,000	[27]
• 1 unit of shredding machine (IDR/unit)	15,000,000	[18]	• Truck rent for digestate distribution (IDR/month)	22,000,000	[29]
• Digestion reactor and equipment (IDR/unit)	1,150,000,000[b]	[18]			

[a] Operational costs for controlled landfill; with currency rate of 1 USD = IDR 13,500.00 [b] Based on estimation according to the available price list

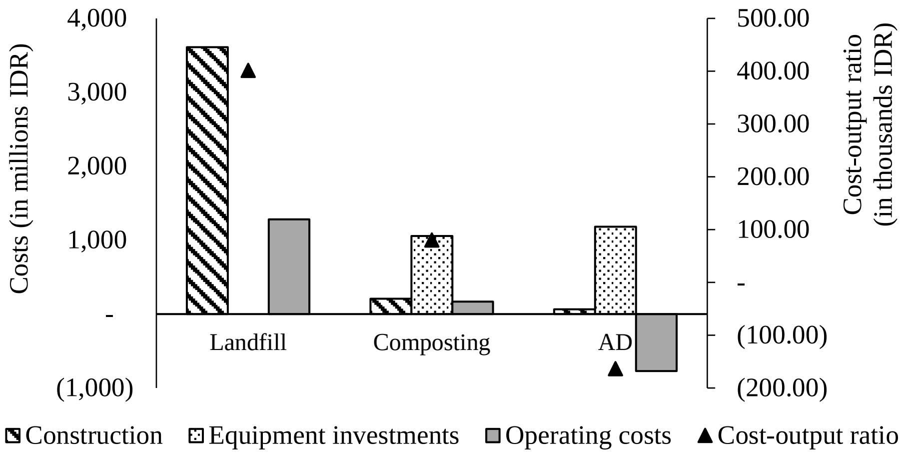

Fig. 1 Comparison of economic performance of two alternatives and baseline scenario

3.6 SWOT Analysis of FVW Management Systems

In general, the SWOT analysis was carried out by considering related governmental aspect and social impacts that may emerge due to the operation of on-site waste treatment in the vicinity of the traditional market. The SWOT analysis was performed in addition to the environmental and economic analysis of the system alternatives (Table 4 and Table 5).

Table 4. SWOT analysis for composting scenario

Strengths	Weaknesses
• GHG emissions per unit waste are 0.01 ton, while the emissions from baseline scenario are 3.52 ton. • The cost-output ratio is five times lower than that from baseline scenario. • Less frequent heavy vehicles movements than in the baseline scenario. • Having simpler operation than anaerobic digestion scenario, those proficient staffs are not required. • Supporting the government targets of reducing solid waste disposal to landfill and utilizing solid waste as a resource.	• Not suitable for the markets with restricted space area, as it requires a larger area than that needed in anaerobic digestion scenario. • Demanding high energy, resulting in lower net energy balance. • Leachate production requires further control measures. • On-site treatment are more prone to be rejected by the surrounding community due to limited environmental awareness and education among the society.
Opportunities	**Threats**
• On-site production of compost offers the benefits to boost the "green" image of businesses through the distribution of compost to the vendors, nearby communities or agricultural lands. • The traditional market may obtain an additional income from compost sales.	• Unclear distribution target potentially stops compost production due to compost accumulation in the facility. Thus, the government should be involved in determining the target sector that can take benefit of the by-product. • Waste segregation should be conducted in a proper manner. Contamination by other waste can lead to less efficient composting process.

Table 5. SWOT analysis for anaerobic digestion scenario

Strengths	Weaknesses
• Possessing a positive net energy balance of equal to 0.12 ton $CO_{2\text{-eq}}$ per ton waste. • Being profitable due to the excess electricity, resulting in the profit of IDR 163,400 per ton waste. • Less frequent heavy vehicles movements than in the baseline scenario. • Having shorter payback period than the composting scenario. • Supporting the government target of reducing solid waste disposal to landfill and saving resources through on-site energy generation.	• The microorganisms involved in anaerobic digestion are more prone to the changes of environmental factor, that a proficient staff is required to obtain an optimum biogas yield. • Start-up installation and microorganism acclimatization are more complex than composting scenario. • On-site treatment is more prone to be rejected by the surrounding community due to limited environmental awareness and education among the society.
Opportunities	**Threats**
• On-site energy generation and digestate production may support recycling target, save more resources and raise the reputation of businesses. • Combining wastewater generated from the market leads to superior digestion efficiencies, resulting in higher energy production.	• Unclear distribution target sector potentially leads to the accumulation of digestate on-site, which would become another environmental problem. Thus, the government should be involved in determining the target sector that can take benefit of the by-product. • Waste segregation should be conducted in a proper manner. Contamination by other waste can lead to the less efficient digestion process.

4 CONCLUSION

Based on the comparison of the environmental and economic performances, presented in the SWOT matrix, it is shown that on-site anaerobic digestion is the optimal solution for FVW management system to be situated in the vicinity of traditional markets in Bandung city, Indonesia. Anaerobic digestion has the negative value of net energy balance indicating beneficial energy production. From the economic point of view, it also has the potential of making the profit of IDR 163,400 per ton waste. As for the on-site composting scenario, it has the cost-output ratio five times lower than the landfill scenario. In addition to that, both the operation of an on-site anaerobic digestion and composting may also eliminate the costs associated with the waste transportation, and reduce traffic congestion. Despite the benefits offered, it is still essential that the government should actively participate in ensuring the availability of target sectors that can make use of compost and digestate as inorganic fertilizer substitution.

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