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Comparison and Evaluation of Large-Scale and On-Site Recycling Systems for Food Waste via Life Cycle Cost Analysis

Kyoung Hee Lee [1], Jeong-ik Oh [2], Kyoung Hoon Chu [3], Suk Hyun Kwon [1] and Sung Soo Yoo [4,*]

1 Technical Institute, Domyoung Engineering & Consulting Corporation, Anyang-si 14057, Korea; khlee1975@nate.com (K.H.L.); ksh6407@chol.com (S.H.K.)
2 Land & Housing Institute, Korea Land & Housing Corporation, Daejeon-si 34047, Korea; ojijp@lh.or.kr
3 Department of Civil and Environmental Engineering, University of South Carolina, 300 main St., Columbia, SC 29208, USA; foreverchu@naver.com
4 Environmental and Plant Engineering Research Institute, Korea Institute of Civil Engineering and Building Technology, Goyang-si 10223, Korea
* Correspondence: yoosungsoo@kict.re.kr; Tel.: +82-10-8863-1569

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Abstract: The purpose of this study was to evaluate the cost-benefit of on-site food waste recycling system using Life-Cycle Cost analysis, and to compare with large-scale treatment system. For accurate evaluation, the cost-benefit analysis was conducted with respect to local governments and residents, and qualitative environmental improvement effects were quantified. As for the local governments, analysis results showed that, when large-scale treatment system was replaced with on-site recycling system, there was significant cost reduction from the initial stage depending on reduction of investment, maintenance, and food wastewater treatment costs. As for the residents, it was found that the cost incurred from using the on-site recycling system was larger than the cost of using large-scale treatment system due to the cost of producing and installing the on-site treatment facilities at the initial stage. However, analysis showed that with continuous benefits such as greenhouse gas emission reduction, compost utilization, and food wastewater reduction, cost reduction would be obtained after 6 years of operating the on-site recycling system. Therefore, it was recommended for local governments and residents to consider introducing an on-site food waste recycling system if they are to replace an old treatment system or need to establish a new one.

Keywords: food waste treatment; on-site recycling system; large-scale treatment system; life cycle cost; cost-benefit

1. Introduction

The daily generation of food waste in South Korea is 13,209 t in 2014 (48,728 t/day), accounting for approximately 30% of total municipal waste [1,2]. While the amount of total municipal waste has been decreasing (2009–2013: 50,015 t/day), that of food waste has been on the rise (2009–2013: 12,978 t/day) [3,4]. Most of the food waste currently generated from houses is being treated through large-scale treatment systems. They consist of a separation/discharge stage using small containers; a collection/transportation stage using trucks; a treatment stage using large-scale composting, feeding, and anaerobic digesting facilities; and a final disposal stage via wastewater treatment facilities [5].

As large-scale treatment systems take approximately 2–3 days to collect and transport discharged waste, and cause corruption, odor, and leachate problems [6]. In addition, food wastewater of high concentration is generated during washing and dehydration to remove salt during treatment, which increases the operating cost of the connected wastewater treatment plants as well as sludge generation [7]. To solve such problems, on-site recycling systems, which recycle food waste through small-scale devices without collection and transportation and consume the byproducts on-site, have recently been studied and introduced. Some kinds of on-site recycling systems currently introduced include garbage disposers, household disposal machines, automatic vacuum waste collection (AVWC) systems, and small-scale composting and feeding. Among them, use of disposers is limited due to legal problems, small-scale feeding emits odor, and operational costs of AVWC and household disposal machine are too expensive. Therefore, small-scale composting technology is most often introduced into on-site recycling systems [8–10].

Before installing on-site recycling systems, economic efficiency as well as user convenience and recycling rate must be confirmed. As food waste treatment facilities are a part of the social infrastructure installed and operated by local governments and used by residents, it is difficult to install and operate them if their economic efficiencies are insufficient for local governments or residents [11]. In South Korea, studies on on-site recycling systems are still in the nascent stage [12,13]. Studies on economic efficiency analysis are insufficient, and some previous research has focused on economic efficiency analysis only from the separation/discharge stage through the collection/transportation and treatment stages [14]. Thus, no studies have considered the effect of the final disposal and byproduct utilization stages on the economic efficiency.

Korean indicators of the benefits of social infrastructure such as water supply system, drainage system, and wastewater system with regard to economic efficiency evaluation are significantly insufficient compared to those of the major developed countries [15,16]. In particular, there are significant differences in the indicators related to environmental benefits [17]. As such, the economic efficiency analysis currently employed in Korea does not sufficiently evaluate some cost components such as environmental and social costs for large environmental infrastructure developments and it as a challenge to reach mutual agreement between project stakeholders. The environmental benefits of on-site recycling systems are expected to be large because they generate less food wastewater and greenhouse gas emissions compared to the existing large-scale treatment systems, but previous studies on the economic efficiency evaluation failed to appropriately reflect benefits due to resource circulation [18,19]. Therefore, studies that consider such benefits are required.

The purpose of this study was to evaluate the costs and benefits of on-site food waste recycling systems using Life-Cycle Cost (LCC) analysis, and to compare them with the existing large-scale treatment systems. For more accurate evaluation, the economic efficiency analysis was conducted from the perspective of local governments and residents. Besides the separation/discharge, collection/transportation, and treatment stages, this study also considered final disposal of foreign matter and byproduct utilization as part of the system boundary. Furthermore, the qualitative environmental improvement effects, such as food wastewater reduction, byproduct utilization, and community activation, were indirectly quantified by environmental cost analysis (e.g., greenhouse gas emission trading prices and emission charges) as well as surveys.

2. Material and Methods

2.1. Goal and Scope

In this study, the material flow of food waste was classified into the separation/discharge, collection/transportation, treatment, final disposal, and byproduct utilization stages. For economic efficiency, the cost-benefit analysis was conducted using the net present value (NPV) (Equation (1)).

$$\mathrm{B} - \mathrm{C} = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} \tag{1}$$

where B_t is the benefit at time t, C_t is the cost at time t, r is the discount rate, and n is the service life of the facility (analysis period).

To analyze the total LCC incurred during the whole process, including the planning, designing, construction, operation, and dismantling/disposal of facilities, their LCC during the service life was analyzed. The LCC analysis was conducted in the following order: selecting target facilities, investigating basic assumptions such as discount rates and analysis periods, classifying costs such as initial investment cost and maintenance cost, investigating on-site data for the maintenance cost analysis, and conducting interviews.

2.2. Data Quality and Collection

Since data quality is a major factor influencing the results of the study, it is important to accurately define it prior to analysis. The data collection period in this study is 2013–2017 and the geographical area covers Seoul and the capital area where treatment facilities are located. Data for large-scale composting facilities were collected from eight treatment facilities located in Seoul and the capital area. Among the eight facilities, five provided data through e-mail and telephone inquiries and the data for the remaining three facilities were collected from the reports published by the central and local governments between 2013 and 2017. The average values of the data collected through literature review were calculated. The data from on-site composing facilities were collected by visiting the three demonstration sites under construction and interviewing the decision makers.

2.3. Assumptions and Estimates for the LCC Analysis

For the LCC analysis, it was assumed that the daily average of 1 t of food waste is generated from 1000 households in apartment buildings. This is because one unit with a 100-kg daily capacity is installed per 100 households when an on-site treatment facility is constructed considering the safety factor even though the average daily food waste generation per household is 0.7 kg according to the actual survey data.

The analysis period is the assumed period of the service life. In this study, the fixed asset service life table of the Korea Appraisal Board and expert opinions were consulted to select the LCC analysis period. According to the fixed asset service life table (2013), the service life of a waste treatment facility is 15–20 year. In addition, the service life of each screening, shredding, and mixing device in the treatment facilities calculated according to the expert opinion was 20 years. Therefore, the analysis period was assumed to be 20 years in this study.

The LCC analysis involves the conversion of future costs to current values. The value of money, however, changes over time. Therefore, for the objective comparison of the value of money at different time periods, the time value of money must be converted to a specific time point, and the discount rate is used for the conversion. In this study, the practical discount rate was derived as 5.5% based on the time deposit interest rate of the Bank of Korea and the consumer price index of the Statistics Korea.

2.4. Scenario Construction and Description

2.4.1. Large-Scale Treatment System

Currently, in Korea, food waste unit pricing system is in effect and thus, food waste is separated from municipal waste. More than 97% of the discharged food waste is recycled at recycling facilities, among which the composting facilities account for 38%. The radio-frequency identification (RFID) individual meter unit pricing system, in which food waste discharge per household is measured by each RFID meter installed in each collection container and charges for food waste collection, transportation, and treatment are imposed accordingly, is a representative unit pricing system. As such, treatment systems combining the RFID individual meter unit pricing system and large-scale composting facilities were selected from the existing large-scale treatment systems. Food waste is stored in small containers dedicated to it and then discharged into base collection containers through elevators after the small containers are filled. The discharged food waste is transported to large-scale composting facilities by 3.5-t trucks and processed through screening, shredding, 1st sorting, mixing, fermentation, drying, maturing, and 2nd sorting. Compost is produced as a byproduct of the composting facilities, and food wastewater, as well as foreign material are generated during the treatment process. The food wastewater is transported to wastewater treatment plants and the foreign material is transported to landfills and incineration facilities for treatment (Figure 1).

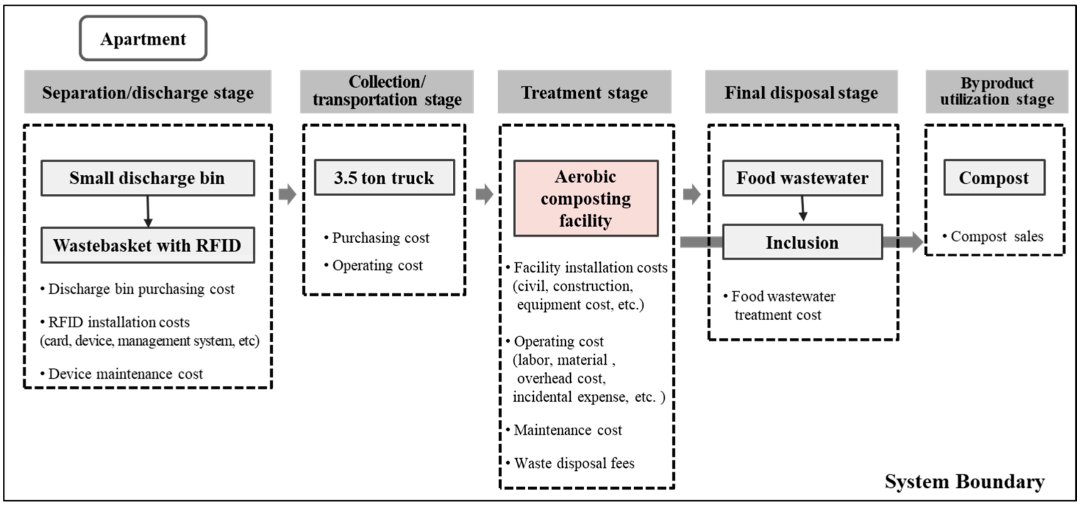

Figure 1. Schematic diagrams of large-scale treatment system.

2.4.2. On-Site Recycling Treatment System

Figure 2 shows the scenario of on-site recycling treatment systems that include small-scale composting, anaerobic digestion, and drying facilities. Among these facilities, the small-scale composting facilities are most widely used ones. As such, in this study, small-scale composting devices that are the miniaturized versions of large-scale compost treatment facilities were selected as the treatment facilities of on-site recycling treatment systems. The treatment capacity of the devices is less than 100 kg/day. Since the on-site composting facilities are installed in apartment complexes and food waste is not discharged to the outside, collection and transportation processes are not required. In addition, because the food waste discharged to the treatment devices is treated immediately, odor and leachate problems that occur in the conventional collection/transportation stage are not addressed. Food waste generated from homes is stored in small containers dedicated to food and then discharged into on-site composting facilities through elevators when the small containers are filled. The food waste is then processed through shredding, mixing, fermentation, drying, and maturing. Compost is produced as the byproduct of the on-site composting facilities, and food wastewater and foreign materials are not generated.

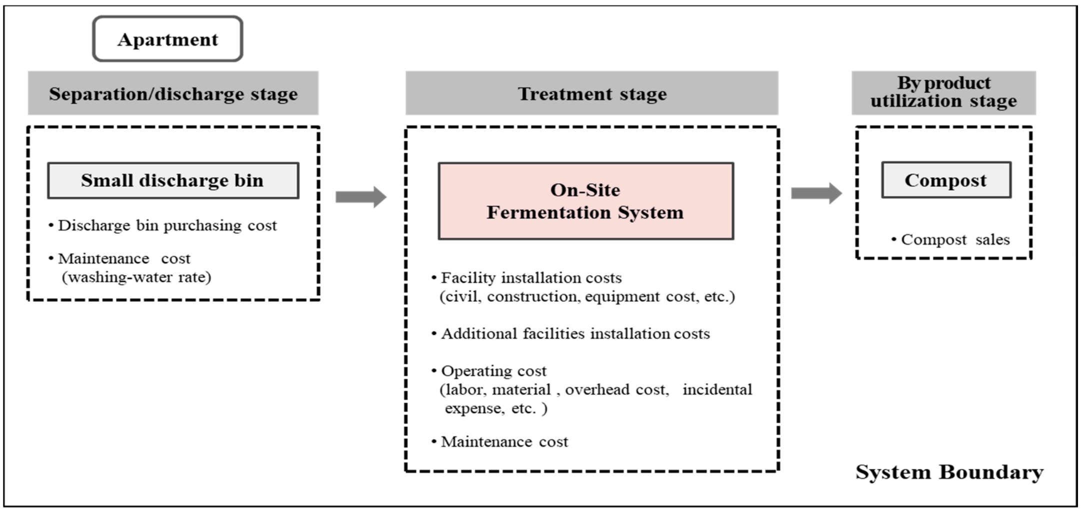

Figure 2. Schematic diagrams of on-site recycling system.

2.5. Analysis Items for Each Stage

The items and collection data considered in this study at each stage for the cost-benefit analysis of local governments and residents were listed in Table 1.

Table 1. Items considered in the LCC analysis and data collected.

		Treatment System			
	Stage	Large-Scale		On-Site	
		Costs	Benefits	Costs	Benefits
Local government	Separation/Discharge	RFID meter installation, telecommunication information management and maintenance	-	-	-
	Collection/transportation	Collection vehicle purchase and operation	-	-	-
	Treatment	Facility installation, maintenance, and management; waste treatment commission	-	Device and auxiliary facility installation and maintenance	-
	Byproduct	-	Compost sales	-	-
	Final disposal	Contamination and food wastewater treatment	-	-	-
Residents	Separation/discharge	Dedicated small containers and cleaning water	-	Dedicated small containers and cleaning water	-
	Collection/transportation	-	-	-	-
	Treatment	Waste treatment commission	-	Device and auxiliary facility installation and maintenance	-
	Byproduct	-	-	-	Compost utilization
	Final disposal	-	-	-	Environmental improvement benefit

In the case of local governments, data related to RFID device installation, telecommunication information management, and consumables and maintenance were collected at the separation/discharge stage. At the treatment stage, the installation, maintenance, and annual operating costs of aerobic composting facilities as well as auxiliary facilities were analyzed. The costs were divided into fixed costs (e.g., facility investment cost, labor cost, and expenses) and variable costs (e.g., maintenance cost and material cost). At the byproduct utilization stage, the case of utilizing the compost produced from large-scale aerobic composting facilities for sales was analyzed.

In the case of residents, at the separation/discharge stage, the material cost of small containers dedicated to food and the water cost for periodically cleaning the containers were considered. As the residents did not pay collection and transportation costs and such costs are included in the waste treatment fee of the apartment management expenses, data on the waste treatment commission were collected. In addition, when on-site treatment facilities were jointly installed and operated by residents, the installation, maintenance, and annual operating costs of small-scale composting facilities as well as auxiliary facilities were analyzed for the service life. The environmental benefits of the reductions in greenhouse gas emissions and food wastewater amounts were quantified. Additional benefits were estimated through the willingness-to-pay amounts for the introduction of eco-friendly facilities capable of resource circulation.

The details of the analysis items for each stage are provided in the following subsections.

2.5.1. Separation/Discharge Stage

The service life of small containers (3-L volume) for food waste was 3 years. As these containers are used in every household, the production cost for 1000 units was considered. In addition, the survey results showed that the containers were generally cleaned once every 3 days and 1 L of water was used for each cleaning. As for RFID meters, 1000 RFID cards with four-year service life were required for 1000 households; thus, 17 RFID meters were required because one device can be used by 60 households. To manage the telecommunication system of the RFID devices, two telecommunication management systems capable of processing information for 500 households were required. The service life of the RFID meter and telecommunication management system was estimated to be 6 years [20,21].

Eight percent of the facility cost and telecommunication management systems was applied every year as the maintenance cost of the RFID devices except for the small containers and RFID cards, which are consumables.

2.5.2. Collection/Transportation Stage

For the collection and transportation of food waste discharged through the RFID meter unit pricing system, the standard price in the price information sheet based on a 3.5-t rotary press-type garbage collector vehicle was applied and the service life of the vehicle was 10 years. For the vehicle operation, the average cost of the intercity operation cost and the city-to-rural area operation cost were applied.

2.5.3. Treatment Stage

Large-Scale Treatment System Facility (Aerobic Composting)

The facility investment cost and the operation cost of large-scale aerobic composting facilities were estimated based on the related industry design data, relevant reports, and basic statistical data provided by the Ministry of Environment. For target facilities, the facility investment cost was estimated considering the civil engineering cost, construction cost, construction equipment cost, machine cost, and electrical equipment cost. Among them, the machine cost and electrical equipment cost include transportation equipment and other auxiliary facilities in addition to major unit devices and the service life of 20 years was applied.

Operation expenses for facilities were largely classified into fixed costs, variable costs, incidental costs, and value-added tax. The items that corresponded to the fixed costs were divided into labor costs (managerial/operational) and management costs (insurance premiums, welfare expenditure, training expenses, travel expenses, meeting expenses, communication and postal expenses, and consumable expenses). The variable costs were facility operation costs and divided into maintenance expenses, electricity expenses, fuel expenses (including LNG), oil expenses (including the operation of fork lifts at the facilities), cost of chemicals, water expenses, contamination disposal expenses, auxiliary material purchase expenses (including sawdust), and testing expenses. The incidental costs were divided into general management expenses and corporate profits. The maintenance expenses among the variable costs were set to 20% of the fixed costs; the general management expenses were set to 10% of the sum of the fixed and variable costs; and the corporate profits were set to 10% of the sum of the fixed costs, variable costs, and general management expenses.

On-Site Recycling System Facility (Small-Scale Composting)

The data were obtained through on-site data and the rent and maintenance cost data of a company, which has manufactured and demonstrated the devices in Seoul and the surrounding area.

The facility investment cost of the on-site recycling treatment facility was based on the installation of ten small-scale composting devices with the service life of 10 years. The installation cost of the auxiliary facilities such as pergola, washing station, and storage facilities required for the maintenance of the corresponding facilities was considered. The service life of auxiliary facilities was based on the 20-year service life of building auxiliary facilities.

The fixed cost items among the operating expenses for the facilities were classified similar to the detailed item classification of large-scale treatment facilities. The labor cost was based on the average worker's wage for monthly management/service completed four times per unit, with one-hour service per management exercise. The variable costs, however, only considered the maintenance expenses, electricity expenses, and the expenses of wood biochips consumed by the small-scale composting device. The electric power was based on the operation of the device for 12 months (i.e., 360 days) and it was assumed that 100 kg wood biochip was consumed monthly by each device for small-scale composting based on the data from the company and the on-site data. Besides, the maintenance expenses (20% of fixed costs), the general management expenses (10% of fixed costs + variable costs) among auxiliary expenses, and corporate profits (10% of fixed costs + variable costs + general management expenses) used the same ratios as large-scale treatment facilities.

Municipal Waste Treatment Fee

The Korean law requires the wastes to be treated by one who is responsible for the generation of the waste. The treatment by residents, however, is impossible practically, therefore local governments operate community collection and treatment facilities and charges the cost to residents, which is defined as "municipal waste treatment fee" in this study.

In the case of operating the existing large-scale treatment facilities, local governments consider the municipal waste treatment fee as the operating profit, while residents consider it to be an expense for processing food waste. The expense is imposed according to the amount food waste generated using RFID. As the expense is different for each local government, the average value of $0.07/L is applied in this study.

2.5.4. Final Disposal

Food Wastewater Treatment Cost

When food waste is treated into aerobic compost in large-scale facilities, food wastewater is generated. The generated wastewater is treated at the connected wastewater treatment plants. Aerobic composting facilities, in particular, produce more wastewater than other types of food waste treatment facilities. The main sources of the generated food wastewater are the process water added for the quality of the final compost and the supernatant liquid desorbed from the dehydrator.

This study applied the facility investment cost and operation cost of the wastewater treatment facility according to the organic material load to estimate cost of treating food wastewater generated from large-scale treatment facilities in connected wastewater treatment facilities. The amount of food wastewater generated was set to 0.92 t.

Environmental Improvement Benefits Due to Reduction in Food Wastewater Generation

Unlike large-scale treatment facilities, on-site treatment does not generate food wastewater or contaminants. Therefore, loads due to contamination treatment do not occur in environmental treatment facilities. To quantify this as a benefit of environmental improvement, the basic charge on biological oxygen demand (BOD) among emission charge systems was applied. The basic charge was introduced with purely economic purposes rather than emission reduction purposes for pollutants emitted below the allowed emission limit. It is levied on organic substances (BOD) and suspended solids (SS).

In this study, the environmental improvement benefits due to the absence of food wastewater in on-site treatment were indirectly quantified by the emission charge. For treating 1 t of food waste generates 0.92 t of food wastewater, the BOD concentration of the food wastewater was assumed to be 70,000 mg/L. The basic charge of $0.22/kg and the annual index of 5.556 for 2017 were applied. For other coefficients, such as site charge coefficient and area coefficient, basic coefficients were used.

Benefits Due to Greenhouse Gas Reduction

Unlike large-scale treatment facilities, on-site treatment requires no treatment of food wastewater in the connected wastewater treatment plants. In addition, due to the CO_2 mitigation effect on account of the use of the byproduct as compost, the CO_2 generation was estimated to be −43.88 kg CO_2/t of food waste in on-site treatment facilities while it was 37.79 kg CO_2/t in existing treatment facilities in our previous study [22].

These values were converted to greenhouse gas emissions trading price to estimate the benefits. The emission trading price was based on the average price of the Korea Exchange's allocation, offset, and external business performance reference price in 2017.

Byproduct Utilization

When the small-scale composting technology of on-site treatment facilities is applied, the amount of compost produced is 0.1 t based on the 90% reduction rate. The benefit of using the compost for planting trees in the complexes was estimated. The unit price was $0.05/kg, which was the price of the compost produced in the public composting facilities of Seoul where the demonstration projects were performed.

2.6. Estimation of Willingness to Pay (WTP)

WTP was analyzed to reflect social and public benefits of resource recycling technology by quantifying the effects of environment improvements perceived by residents. In addition to cost saving and cutting of environmental tax through reduction of actual greenhouse gas, the comfort, convenience, and contributions to environment perceived by consumers have some qualitative aspects. The economic evaluation reflects these aspects by using Analytic hierarchy process (AHP) and others, and this study performed surveys to reflect these economic values as a benefit after quantification.

We analyzed the expected technological effect and the environmental benefits of on-site food waste recycling systems and conducted a survey on Willingness to Pay (WTP) for quantification. To evaluate the perception of residents currently using the treatment system, one-on-one surveys were conducted by a survey company, the Gallup Korea, with 400 residents living in an apartment complex where a pilot project of an on-site food waste recycling system is in operation. The survey design and respondent characteristics are shown in Table 2.

Table 2. Design of survey for WTP estimation and respondent characteristics.

	Category	Value
Survey	Target	A woman aged 20 or over who lives in an apartment.
	Area	Ansan-Si (boner village) Seoul (Gangnam, seocho, songpa) Goyang-Si (Ilsan) Sungnam-Si (Bundang)
	Method	Face to face interview
	Period	12–25 January 2017 (14 days)
Sample	Number Method	400 people (valid sample) Quota sampling

3. Results and Discussion

Costs and benefits of introducing a large-scale treatment system and an on-site food waste recycling system were estimated using LCC analysis for a local government and residents. Economic benefits of the two treatment systems were comparatively analyzed. The analysis period was set at 20 years based on the service life and 5.5% was applied as the real discount rate. For a more accurate analysis, food waste material flow was classified into various stages: separation/discharge, collection/transportation, treatment, final disposal, and byproduct utilization. Qualitative environmental improvements were quantified and added to the benefits.

3.1. Cost-Benefit Analysis for Local Governments

3.1.1. Analysis Results of the Large-Scale Treatment System for Local Governments

Given that a local government has operated a large-scale food waste treatment system for 20 years, costs and benefits were estimated as shown in Figure 3.

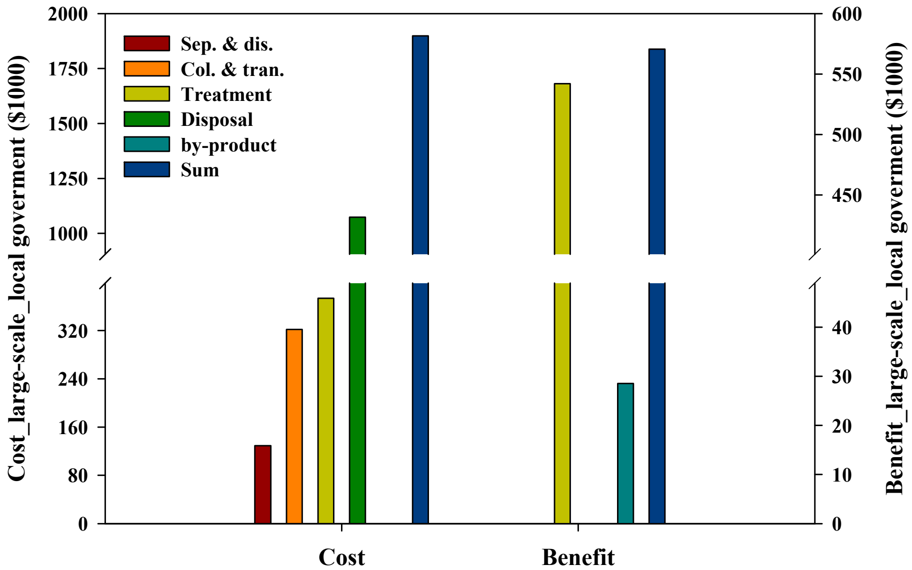

Figure 3. Cost-benefit analysis results for a large-scale food waste treatment system for a local government.

The total cost was estimated to be $1,898,222. The costs of separation/discharge, collection/transportation, treatment, and final disposal were $129,223, $321,894, $373,690, and $1,073,413, respectively. Among these stages, the final disposal stage incurred the highest cost, likely because Korean food, in general, has high salt concentrations by nature, which generates a considerable amount of food wastewater throughout the process of washing the food waste for composting. The cost incurred at the stage of byproducts utilization was $0.

Costs generated for each item considered at each stage were $6024 for RFID card production and distribution and $71,166 for RFID meter production and installation in the stage of separation/discharge. Telecommunication control system management and equipment maintenance costs were $17,908 and $34,125, respectively. At the collection/transportation stage, the purchasing cost of a 3.5-ton truck and the maintenance cost were $99,440 and $222,455, respectively. The costs estimated for treatment were categorized into the initial investment cost and the maintenance cost. The initial investment cost included civil engineering cost, construction cost, machinery cost, and electronic equipment cost and were $9079, $18,759, $88,201, and $13,251, respectively. Included in the item maintenance cost, the labor cost, incidental cost, and value-added tax were $64,374, $36,169, and $20,609, respectively. Costs of insurance, benefits, education and training, traveling, meeting, telecommunication, and supplies were estimated to be $11,552. In addition, the materials cost that includes electricity, fuel, oil, chemicals, water, and impurity treatment was estimated was $96,459, the highest portion of the maintenance cost. The cost of final disposal was $1,073,413 when the treatment cost for food wastewater at wastewater treatment facilities was considered.

Benefits of installing and operating a large-scale treatment system were $570,563 for a local government. Benefits were generated in the treatment and the byproduct utilization stages among the material flow stages. Benefits gained in the stages of separation/discharge, collection/transfer, and final disposal were $0. Those gained in the treatment stage were the commission for food waste treatment ($0.07/L) charged to the residents, $542,025. The benefit gained in the byproduct utilization stage was the income ($28,538) gained by the sales of the byproduct compost produced at the composting facilities.

3.1.2. Analysis Results of On-Site Food Waste Recycling System for Local Governments

Given that a local government introduced an on-site food waste recycling system treatment, the cost-benefit analysis results were presented in Table 3.

Table 3. Cost-benefit analysis results of on-site food waste treatment system for a local government.

Type	Stage	Item	Cost ($)	Benefit ($)
On-site recycling system	Separation/discharge	-	-	-
	Collection/transportation	-	-	-
	Treatment	Production and installation of Fermentation-extinction equipment	280,111	-
		Auxiliary facilities production	4417	-
		Maintenance	13,766	-
		Operation management	498,436	-
	Final disposal	-	-	-
	Byproduct utilization	-	-	-

The total cost of the introduction of an on-site food waste recycling system was $796,730 for a local government. The cost was incurred in the treatment stage. The system equipment of an on-site food waste recycling system was installed within the apartment complex. Therefore, the system does not require the collection or transportation; thus, incurs no costs in the collection/transportation stage. In addition, no final disposal cost was incurred because the bio wood chips reduced the salinity of the food waste, which generated no food wastewater. The production and installation of a small-scale composting equipment of a 10-year lifespan was $280,111. The cost for auxiliary facilities required for the maintenance of the equipment including a pergola, sink, and storage was $4417. The maintenance cost including the purchase of bio wood chips and electricity was $43,766. The management cost including the labor cost and telecommunication was $498,436.

The result of the benefit analysis for a local government following the introduction of on-site food waste recycling system was $0 because residents use the entire byproduct compost generated from the on-site recycling system. As a result, the local government was unable to generate revenues from the sales of the compost unlike in the case of the large-scale treatment system. Because there was no need to contract a service for large-scale collection, transfer, and treatment, the local government could not charge any food waste treatment fee to the residents. However, this does reduce costs incurred in sending food wastewater and impurities to treatment facilities and treating them. The introduction of on-site food waste recycling systems will be ultimately cost-effective for resource recycling.

Figure 4 shows the economic benefits of replacing a large-scale treatment system with an on-site food waste recycling system estimated for a local government. There were no benefits gained by the local government by this replacement. Nonetheless, the costs of installing equipment and maintenance were approximately three times cheaper compared to the large-scale treatment system and there was no food wastewater treatment cost, which accounts for the greatest portion of the cost of operating a large-scale treatment system. Therefore, the annual loss for the local government would largely decrease after the replacement. Because the cost reduction occurs starting from the initial phase of introducing the on-site recycling system, it is advantageous for local governments that need to replace an old food waste treatment system or establish a new one to consider an on-site recycling system.

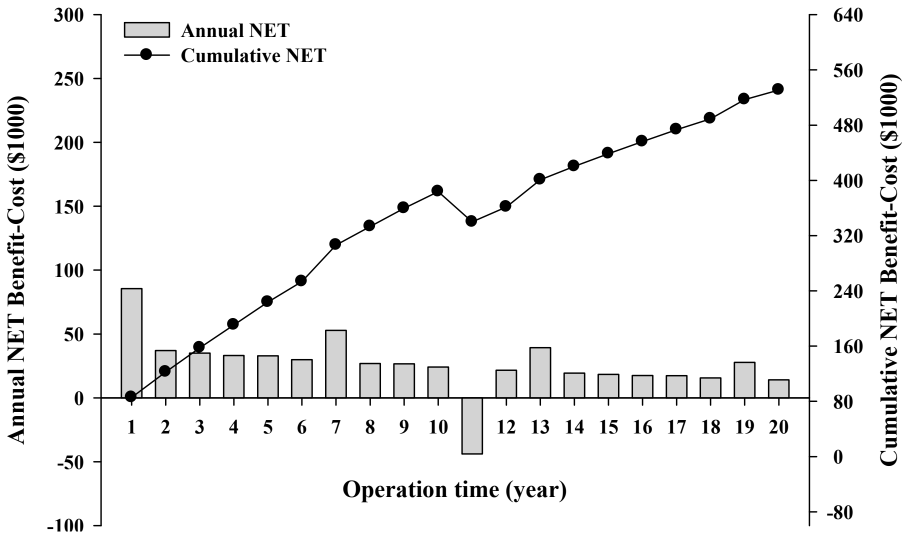

Figure 4. Costs and benefits of replacing large-scale treatment system with on-site food waste recycling system for local governments.

3.2. Cost-Benefit Analysis for Residents

3.2.1. Analysis Results of Large-Scale Treatment System for Residents

Given that a large-scale treatment system composed of RFID meter and composting facilities was used by residents, the results of the cost-benefit analysis for residents are shown in Table 4.

Table 4. Cost-benefit analysis results of food waste large-scale treatment system for residents.

Type	Stage	Item	Cost ($)	Benefit ($)
Large-scale treatment system	Separation/discharge	Small container purchase	40,193	-
		Small container cleaning	668	-
	Collection/transportation	-	-	-
	Treatment	Food waste treatment commission	542,025	-
	Final disposal	-	-	-
	Byproduct utilization	-	-	-

The cost of cleaning and purchasing small containers was $40,193 and $668, respectively, and associated with releasing domestic food waste to the RFID equipment at the stage of separation/discharge in a large-scale treatment system. The local government charges a food waste treatment commission to residents to partially cover the costs incurred in treating large-scale food waste; $542,025 was incurred to the residents at the treatment stage of the large-scale treatment system. This cost was one of the benefits for the local government. The survey results revealed that there was no cost incurred for the residents at the final disposal and byproduct utilization stages. Therefore, the total cost for the residents that use the large-scale treatment system was $582,886.

The benefit for the residents was $0 because the local government operates the composting facilities, thus owns the rights to the compost generated by treatment.

3.2.2. Analysis Results of On-Site Food Waste Recycling System for Residents

Residents, who generate food waste and pay for the commission, experience the benefits of increased convenience of the facilities, pleasantness of the surrounding environment, improved sense of community among the residents as well as reduced treatment commissions or maintenance costs. The costs and benefits of introducing the on-site food waste recycling system through cost sharing by residents were analyzed considering these factors. The results are shown in Figure 5.

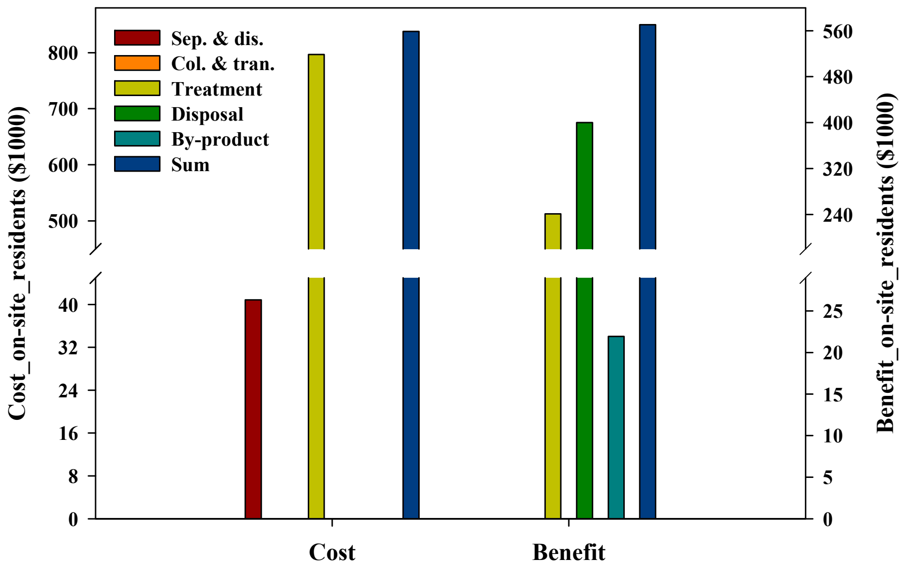

Figure 5. Cost-benefit analysis results of on-site food waste recycling system for residents.

The total cost of introducing an on-site recycling system was $837,590. The cost of the separation/discharge and treatment stages was $40,860 and $796,730, respectively. Because the system recycled the food waste on site, the cost of collection/transportation of wastes was $0. No wastewater was generated owing to bio wood chips that treated the salinity of the food waste. Therefore, the cost of final disposal to the residents was $0.

Costs incurred at the separation/discharge stage included the costs for purchasing small containers and cleaning after releasing the domestic food waste to the RFID meter ($40,193 and $668, respectively) similar to the large-scale treatment system. In case of treatment stage, we assumed that 1000 households at an apartment complex installed 10 pieces of equipment with a daily treatment capacity of less than 100 kg. The cost of producing and installing a small-scale composting equipment with a 10-year service life was $280,111. The cost of producing and installing auxiliary facilities such as a pergola, sink, and storage required for equipment maintenance was $4417. Maintenance cost including the purchase of bio wood chips and electricity was $13,766 and the management cost including labor cost and telecommunication equipment was $498,436.

The benefits of an on-site food waste recycling system for residents were $662,827. Approximately 0.1 t of compost was generated per ton of food waste in the treatment stage. Benefits was estimated as $21,952 if residents use the entire compost for landscapes and shared vegetable gardens within an apartment complex. A previous study [22] found that the introduction of on-site food waste recycling system reduced greenhouse gas emissions more than twice the amount that a large-scale treatment system could. In terms of greenhouse gas emission reductions, the benefit calculated based on the greenhouse gas emissions trading price was $6939. The environmental benefits of no food wastewater generation were indirectly quantified using the emissions charge policy ($399,837). To calculate WTP, a survey was conducted with a total of 400 participants, 68.5% of which reported the environmental benefits of introducing the on-site food waste recycling system. The survey revealed that each household was willing to pay additional $1.55 per month apart from the food waste treatment commission of $1.64. Therefore, 1000 households were willing to pay $18,551 every year and an additional cost of $234,099 for 20 years with a discount rate applied.

The introduction of on-site food waste recycling system would incur an annual cost of $9103 when the residents of 1000 units in an apartment complex share the cost. The total cost was estimated to be $174,763 for a 20-year period considering the NPV. The cost was approximately 334% lower than the cost associated with the large-scale treatment system. The analysis was conducted on the costs and benefits of replacing the existing large-scale treatment system with an on-site food waste recycling system and operating the new system for 20 years. The results are shown in Figure 6.

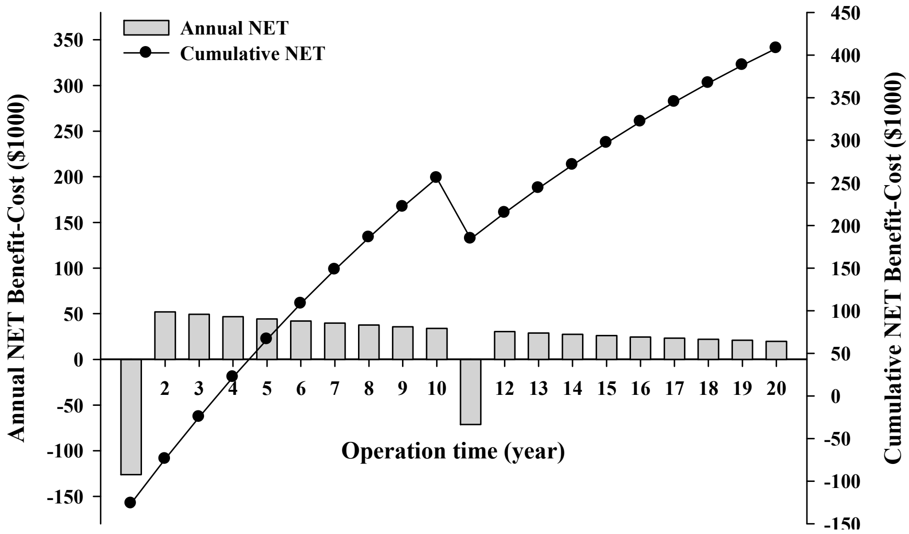

Figure 6. Costs and benefits of replacing large-scale treatment system with on-site food waste recycling system for residents.

In the early period of introducing an on-site food waste recycling system, establishing new treatment facilities and other additional facilities costs approximately $126,173. However, these additional costs were compensated by reduced maintenance costs and increased benefits as the system operation proceeds. The breakeven point was reached after six years of operation. The analysis shows that the cost was reduced by approximately $407,911 when the system was operated for 20 years or more.

The result of this study was different from those of previous studies [14,18,19], according to economic efficiency of large-scale treatment system was better than that of on-site treatment system. Therefore, this study was determined to enhance the validity of the on-site recycling system which has been currently promoted by Korean government under the slogans such as resource cycling and green growth and contribute to decision makings by local governments which intend to introduce a processing system of food wastes, due to development of new towns or deterioration. The main reason why the result of this study was different from that of previous ones was resulted from the introduction of quantified standard environmental indicators in an analysis of LCC. It was determined that the quantification of environmental indicators may be activated, in the analysis of LCC in social infrastructure facilities which can resolve environmental problems, based on this study.

4. Conclusions

This study estimated the costs and benefits using LCC analysis to promote the on-site food waste recycling system, which is a new domain currently under research. We analyzed the on-site food waste recycling system in comparison to the existing large-scale treatment system and evaluated the economic benefits of introducing an on-site food waste recycling system. For a more accurate assessment, economic benefits were analyzed with respect to local governments and residents. Qualitative environmental improvements were indirectly quantified and were considered as benefits.

Cost-benefit analysis of the existing large-scale treatment system and an on-site food waste recycling system was conducted for a local government. Costs of the large-scale and the on-site food waste recycling system were $1,898,222 and $796,730, respectively, and the benefits were $570,563 and $0. The economic benefits of replacing the large-scale treatment system with an on-site food waste recycling system for the local government were estimated. The results showed that the on-site food waste recycling system brings no benefits to the local government; however, the cost of equipment installation and maintenance of the new system was much lower compared to the cost of the large-scale treatment system. There is no food wastewater treatment cost in the new system, while it accounted for the greatest portion of the total cost of operating the large-scale treatment system. Thus, the annual cost for a local government largely decreased if the on-site system is used. Cost reduction occurred starting from the early period of the on-site food waste recycling system operation. Therefore, it was recommended for local governments to consider establishing an on-site food waste recycling system if they are to replace an old food waste treatment system or need to establish a new one.

The cost-benefit analysis of the two treatment systems was also conducted for residents. The costs of the large-scale and on-site food waste recycling systems were $582,886 and $837,590, respectively, and benefits were $0 and $662,827. The economic benefits of the replacement were also estimated for residents. The results revealed that an additional cost of $126,173 was incurred in the early period of the on-site food waste recycling system operation due to the costs of establishing new treatment facilities. However, the gap was later bridged by the reduced maintenance cost and increased benefits as the operation proceeded. The breakeven point was reached after six years of operation. If the system is operated in a continuous manner for 20 years after that point, costs would be reduced by approximately $407,911.

In conclusion, the on-site food waste recycling system that recycles food waste generated in apartment complexes provides economic benefits to both local governments and residents. Further, it allows residents to actively manage the benefits generated from the recycling of wastes and the use of byproducts. It is expected that this will, in turn, provide the public with a better living environment and to stimulate the local economy and resource recirculation.

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