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A Cost Analysis of Food Waste Composting in Taiwan

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Abstract: Taiwan's Environmental Protection Administration (EPA) has enacted a food waste recycling policy since 2003 as an alternative of landfill and incineration for the final disposal of municipal solid waste. Recycled food waste is currently seen as a valuable material, especially when appropriate technology is developed. This paper conducts a cost/benefit analysis based on six cases of food waste composting plants in Taiwan, finding that (1) the composting of food waste may yield the most net benefit compared to other applications of today; (2) the production cost of compost ranges from NT$ 2897–23,117/tonne; (3) the adoption of more automatic technology may reduce operation costs and, thus, a closed composting system with mechanical aeration may be more cost effective; (4) the output is a determinant of affecting production costs and private firms are more competitive in production costs than government-affiliated composting units; (5) all of the government-affiliated composting units face a negative profit and thus they are required to make use of the market value of the produced compost to achieve economic viability; and (6) a subsidy to the compost producer is needed to expand the market demand as the food waste recycled can save the disposal cost of municipal solid waste (MSW) incineration.

Keywords: cost analysis; composting; mechanical aeration; food waste; recycling

1. Introduction

In 2014, Taiwan's municipal solid waste (MSW) disposal by incineration and landfills amounted to 3,189,000 tonnes and 83,000 tonnes, accounting for 43.27% and 1.14% of MSW generated, respectively, and the rest (55.59%) is recycled [1]. The total amount of garbage recycled for composting, material recovery, or remanufacturing, including food waste, recyclable resources, and bulk waste, increased from 1,057,000 tonnes in 2001 to 4,097,000 tonnes in 2014 with an annual growth rate of approximately 20.55%. The high growth rate of recycled MSW implies that the concept of MSW has been changed from waste into valuable resources.

Considering potential environmental impacts and public health risks arising from the incineration of food waste, the Taiwan EPA revised its policy to reduce the food waste disposal through incineration or landfill. A policy was enacted to encourage food waste recycling and reuse by subsidizing each county and township to establish the food waste recycling systems at the beginning of the 2000s. Many researchers argue that MSW treatments by means of recycling, recovery, and reuse should be adopted as a priority in MSW management [2–6]. Among these treatments, biological composting is generally considered to be a rapid and simple process to stabilize and reduce the waste mass. It can be said to be the most natural way of recycling through biological reactions to achieve environmental self-cleaning among the various disposal options [7] and superior to traditional treatments (i.e., incineration and sanitary landfill) from the viewpoint of reducing greenhouse gases (i.e., CO_2 and CH_4), emissions, and other pollutants [2–6,8,9]. Furthermore, Andersen et al. [10] (employ the life cycle assessment (LCA) method to assess the benefit of home composting of food waste in Denmark. His study suggests that the replacement of fertilizers may generate a significant environmental benefit. Lim et al. [11] present an overview on the feasibility of composting from the organic waste and the environmental impact and economic potential of composting. They suggest that composting can be seen as a sustainable means for MSW management. The cost/benefit analysis shows that composting is more attractive than landfilling because of the reduction in the amount of organic waste that is usually treated by landfill [12]. The recycling of food waste by compost is beneficial to agricultural land and yields fewer environmental impacts compared to other disposal processes, like landfilling and incineration [13,14].

In practice, the food waste recycled can be used as raw materials for composting plants to produce fertilizers (compost) and biogas, or for feed mills to produce pellet feed. The cost and benefit of various applications for recycled food waste have not been fully developed and quantified. Accordingly, the purposes of this article include (1) comparing the various applications for food waste recycled through a qualitative survey; and (2) conducting a cost/benefit analysis of biological compost production through case studies to shed light on the choice of appropriate application technologies. The accompanied environmental impact for each application may form barriers to the recycling of food waste and, thus, we also discuss these scenarios.

2. Current State of MSW Treatment in Taiwan

The material balance of Taiwan's MSW in 2014 is depicted in Figure 1, based on the data provided by the Environmental Protection Administration [1]. All of the municipal solid waste generated is sorted by households, obligatorily. MSW generated is sorted and classified into four streams: general MSW, bulk waste, food waste, and recyclables, such as waste paper, plastics, metals, glass, etc. General MSW is collected every day; recyclables 2–3 days in a week, and bulk waste once or twice in a year. Each waste stream is characterized by its waste fraction and the subsequent treatment method. Figure 1 reveals that averagely speaking each unit of Taiwan's MSW generated in 2014 contains 44.41% general MSW, 0.89% bulk waste recycled, 44.92% garbage recycled, and 9.78% food waste recycled. Each unit of general MSW collected and delivered to final disposal units, excluding recyclable waste resources in 2014 contains 39.21% of food waste, 38.31% of paper, 15.66% of plastics, 2.56% of incombustibles, and the balance comprises 4.26%.

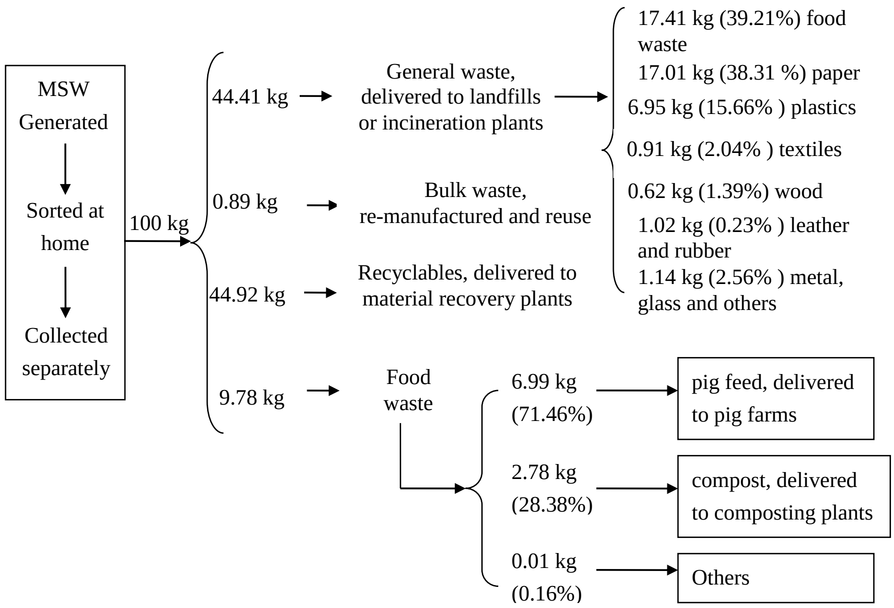

Figure 1. Schematic representation of Taiwan's MSW management practice in 2014. Data source: Environmental Protection Administration [1].

Generally speaking, anaerobic digestion and aerobic composting are seen as two effective methods for treating various types of organic waste [15] but the anaerobic digestion made few contributions to the treatment of the food waste recycled in Taiwan. According to Environmental Protection Administration [1], food waste is categorized into three applications, which include pig feed, composting, and others. The use of food waste for pig feed increased from 140,090 tonnes in 2003 to a peak of 588,808 tonnes in 2012, and then declined to 514,770 tonnes in 2014, while the use for composting increased from 23,092 tonnes in 2003 to a peak of 261,532 tonnes in 2011, and then dropped to 204,472 tonnes in 2014. The other application of food waste results in no large changes, fluctuating between 1132 tonnes to 8661 tonnes. Encouraged by the national development program entitled "challenging the 2008 green industry-resources recycling, recovery and reuse" enacted in 2003, all of the 319 townships in Taiwan had established their recycling systems by 2006 and, thus, the food waste for composting formed a still higher growth trend than the other two applications after 2006. Totally, food waste collected grew greatly from 168,601 tonnes in 2003 to a peak of 834,541 tonnes in 2012 and then declined to 720,373 tonnes in 2014.

Composting of food waste into organic fertilizers accounts for 28.38% of total food waste recycled in 2014. It is a traditional method through a natural aerobic process of organic matter biodegradation. Currently, the composting technology of food waste has been proved to be technically and economically viable enough to avoid the risk of pathogen infections. Currently, a variety of composting systems are installed and operated in Taiwan, including open systems and in-vessel systems, but most of them are manually operated with small to medium capacity. The basic process of the composting plant is presented in Figure 2. The food waste sorted by households is collected together with general MSW and transferred to landfills or incineration plants that serve as transfer stations. The collected food waste is transported to composting plants and stored in open fields or in the bin after uploading. The mechanical pre-treatment unit for the shredding of large objects through the belt conveyor is used to reduce the size of substrates before the removal of inappropriate waste. The size reduction can increase the surface area for aeration and microbial action and, thus, the decomposition can be easier for harder materials like fruit peel or wood.

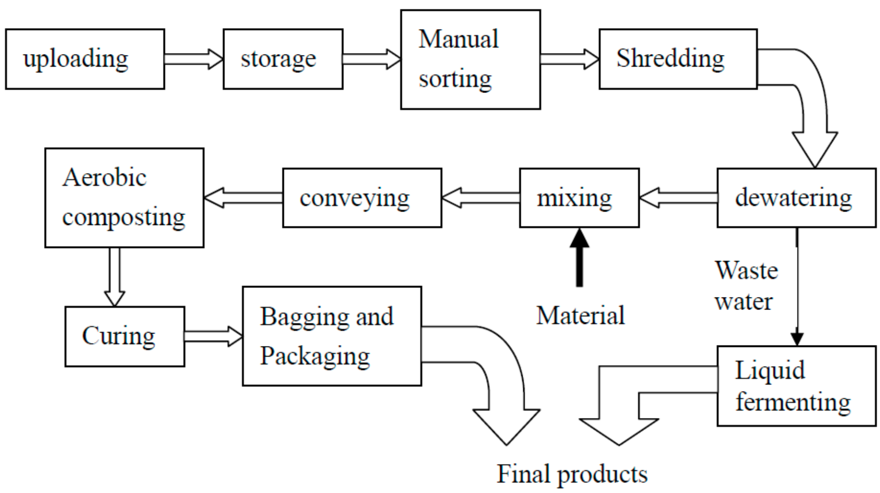

Figure 2. The flow sheet of composting plants.

The food waste after the shredding operation is mixed with some supplementary materials as the composting process requires considerable quantities of supplemental materials necessary to be mixed with the input material of food waste to maintain a good composting condition at a water content of 50%–60% and C/N ratio of 26–35 for the food waste composting. In practice, many types of materials, like rice husks, shrimp shells, and woody waste are slated as the supplementary material. The main purpose for the adding of supplementary materials is not only to adjust the chemical properties (water content and C/N) for a proper fermentation of organic waste, but also to optimize the physical structure that air can distribute inside the feedstock equally in the fermentation process.

After mixture, the organic waste is conveyed into the composting unit. A regular windrow turning (about twice a week) can improve the speed of the process and the quality of the product. A time span of several days to months is needed for the aerobic waste composting process to stabilize the food waste under controlled aerobic conditions, depending on the process automation and inoculation. The mature compost mix is moved to another space and waits for post-fermentation, which takes about 45–60 days. The final product of compost is screened and bagged into 25 kg or 40 kg bags.

Theoretically, all degradable organic waste can be composted, but only a few types, like food waste and sludge can be recovered by a dedicated plant. The composting process is not only easy, but flexible. The investment cost for composting facilities depends on the choice of composting capacity and the level of automation. Generally speaking, the choice of optimal composting process and capacity needs to make a trade-off in terms of labor costs, land costs, capital costs, and other parameters.

Briefly speaking, the major benefits of food waste recycling include (1) the saving of final disposal costs either by landfill or incineration; (2) the extension of service life for incineration plants; and (3) the avoidance of consequent impacts on the environment influenced by landfill or incineration. As the food waste consists of high organics and water content derived from the kitchen residue, the incineration or landfilling of food waste may generate a significant impact on greenhouse gas emissions, hazardous gases (i.e., hydrogen sulfide, ammonia), and leachate [16,17]. The incineration process consumes a lot of energy and the lifecycle of the incinerator could also be reduced because of the high content of moisture and salt in food waste. Probably the most controversial pollutants from incinerator emissions are the categories of toxic chlorinated organics. Secondary emissions may occur at the landfill or incineration process for food waste disposal. Landfill gas is generated during the decomposition of organic waste in landfills, generating high impacts on the warming effects. Due to the significant greenhouse gas emission from landfills or incinerators, it is necessary to make a change to mitigate future climate change impacts. Furthermore, composts produced from food waste are nutrient-rich organic fertilizers for soil improvements [18,19] and yield a positive impact on soil structures, increasing its microbial population and activity [20].

3. Research Methods

A quantitative analysis is conducted to evaluate the cost and benefit of biological compost production. In total, six composting plants are purposely selected as case examples. In order to compare the performance of the operating modes between government-owned and private firms, three government-affiliated composting units (GACU) and three private firms are selected. Secondly, we select the high, medium, and low size of the facilities for each category (the government-owned and the private facilities) to examine how automation and the size of the plants impact the cost and benefit. The data connected with the composition of inputs, production capacity, bulking material, the consumption of electricity and fuel, operating costs, construction costs, and the final price of compost are provided by each plant.

According to Environmental Protection Administration [21], almost each township in Taiwan has installed their composting plants in the landfills or incineration plants serving as food waste transfer stations for demonstration use with the financial support of Taiwan EPA, and are operated and managed by the township. A large majority (80%) of these facilities are small- to medium-sized plants. Each plant processes less than 10 tonnes of input materials (food waste) per day, far smaller than the designed capacity due to a lack of profit pressure. The leachate generated from the composting process is easily controlled in delivery to the existing waste water plants located inside the disposal plant (landfills or incineration plants).

On the other hand, there are 31 privately-owned composting plants, which use a mixed organic waste constituting of sewage sludge, food waste, rice husk, animal manures, and industrial sludge [22]. Most of Taiwan's private composting facilities are installed in a steel-framed building with odor control systems, so they are able to effectively mitigate any odor during active composting. The final product of compost by these plants is labeled with 'organic fertilizer' for sale in the market.

3.1. Case Situation

The basic description of these six composting plants is listed in Table 1. The production output ranges from 72 tonnes/year to 18,000 tonnes/year with a variety of production processes at a different degree of automation. Case 1 employs highly technical process, and the technical level of Case 2 and Case 4 is moderate with mechanical windrow turning and aeration in a closed fermentation vessel. The remaining three plants, including Cases 3, 5, and 6 utilize the traditional composting method in an open space with front-end loaders to turn the compost mix. Odor control systems which use water scrubbing units are adopted by Cases 1, 2, and 4 to reduce the odor emission. The organic fertilizers produced by private firms (Cases 1–3) are sold with their own brands through the market system. However, the fertilizer composted by GACUs (Cases 4–6) is hand selected as a gift to the farmers who are willing to recycle food waste.

Table 1. The basic description of the composting plants.

Case	1	2	3	4	5	6
Output (tonne/year)	18,000	9600	850	1300	600	72
Operating mode	Private	Private	Private	GACUs	GACUs	GACUs
mixer and size reduction	yes	yes	yes	yes	yes	yes
fermentation (composting)	closed	closed	open	closed	open	open
Aeration	Mechanical	mechanical	manual	mechanical	manual	manual
Odor control	yes	yes	no	yes	no	no
Turning	Automatic	Front-end loader	Front-end loader	Mechanical system	Front-end loader	Front-end loader
bagging	automatic	automatic	semi-automatic	automatic	automatic	automatic

Case 1: Food waste is composted by an automatic process of an in-vessel composting method to provide optimal composting conditions with an input capacity of 100 tonnes per day, and an output of 50 tonnes per day. A continuously rotating horizontal drum rotating with an aeration system purchased from Italy is installed to control the decomposition process of food waste. An automatic windrow turning machine is used to improve aeration by distributing air throughout the pile and to reduce the maturing time. Accordingly, it can increase the production output and stabilize the product quality. An automatic control system is equipped to control the temperature and oxygen level. Owing to the effective temperature control in the fermentation process the compost produced is assured to be pathogen-free, weed seed-free, and odorless.

Due to the automatic process the composting time is shortened. With the rotating vessel the composting time of converting food waste into compost only takes about 4–7 days. The final product of organic fertilizers is packaged by 25 kg or 40 kg bags via blending the fermented compost with other mineral fertilizers, and sold at a price of NT$ 4000/tonne.

Case 2: A closed and aerated windrow composting method is employed with an input capacity of 50 tonnes/day and an output capacity of 27 tonnes/day. The fermentation process is not so automatic compared to Case 1. A mechanical turning system is installed to turn the windrow twice a day in the first week, once a day in the second week, once for every two days in the third week, and once for every three days in the fourth week. Through the use of the mechanical windrow turning system, the processing time can be shortened and the input labor is reduced. The compost in piles is aerated through the use of air ducts by a 20 hp blower. The provision of oxygen through aeration can be helpful for the growth of aerobic micro-organisms and, thus, increase the speed of decomposition.

Moreover, aeration can support the stable quality of the final product by removing excessive heat, water vapor, and other gases trapped in the pile.

Case 3: A traditional composting method is employed with an input capacity of 5 tonnes/day and an output capacity of 2.36 tonnes/day. This plant is more labor-intensive in the production of compost. All of the production units are manually operated. The total cost of the machinery investment is NT$ 1,596,000, which only covers the shredder, mixer, semi-automatic packaging machine, and front-end loader.

The supplemental materials, including wood sawdust, rice husk, dregs, etc., are added into the food waste and mixed by a mixer to adjust the water content at 50%–60% and C/N ratio at 26–35. Then, the compost mix is piled up on the ground field in a steel-framed building and stands for a long time through natural aeration to produce compost. At the fermentation stage, the windrow is turned up by the front loader regularly to supply more air and maintain the temperature at 55–65 °C. At the maturation stage, the windrow is moved to another building for post-fermentation. The total processing time is about three months from raw material to the final product.

Case 4: A closed and aerated windrow composting method is employed in Case 4 with an input capacity of 9 tonnes/day and an output capacity of 3.6 tonnes/day. The production process is similar to Case 2. The leachate is removed from the shredding machine, via a dewatering unit, and is delivered to a closed fermenting vessel for the production of liquid fertilizers.

Case 5: A traditional composting method is employed with an input capacity of 8 tonnes per day, and an output capacity of 2 tonnes per day. However, the designed capacity is 10 tonnes/day of input food waste. The production process is similar to Case 3. The front-end loader is used for the turning and mixing of windrow for its lower investment costs. No odor control system is installed in this plant. All of the machinery costs NT$ 8,500,000, which covers the shredder, mixer, dewatering unit, screen, and packaging machine.

Case 6: The production process is completely identical to Case 3 with an input capacity of 1.5 tonnes/day and an output capacity of 0.2 tonnes/day. The major difference is the operating mode. Case 6 is affiliated with a township, while Case 3 is a private firm which intends to seek the maximization of profit.

3.2. Assumptions

In order to have a comparative basis, some assumptions are presented for the cost/benefit analysis across all cases, which are stated as follows:

(1) The cost for collection from the households requires the support of collecting trucks, containers, and collectors. For the time being, the Taiwan EPA has established a food waste recycling system, providing sufficient facilities to recycle food waste. The food waste collected is temporarily stored at the transfer station. Each composting plant can receive sufficient food waste for free but needs to pay the transportation cost from the transfer station to the destination.

(2) The main costs are classified into two categories: (i) the fixed cost covering the depreciation and the financial interest for the acquisition of the land, building, and machinery for composting; and (ii) the variable cost including operation and maintenance (O and M) costs, supplemental material costs, labor costs, and electricity, and water consumption costs.

(3) The major capital investment comes from the acquisition of land space and composting facilities. Both land area requirements and capital investment vary with the type of the employed technology and the design capacity. The unit land cost, based on the 2016 average value of agricultural land without buildings in the rural regions, is assumed to be NT$ 4000/m^2 for all cases. Therefore, the total land cost is proportional to the required land area. The composting facility is assumed to cover the shredding, mixing, composting, curing processes, and packaging, excluding the truck and other transportation systems. The service life of the composting facility is assumed to be 15 years. A straight-line depreciation over the lifetime of the fixed assets is

calculated for the depreciation cost of composting facilities. The amortization cost for land acquisition, the construction of the building and the installation of machinery is based on 3% of interest rate. A simple cost analysis without consideration of discounted cash flow is conducted.

(4) The monthly wage is assumed to be NT$ 30,000. The current electricity price NT$ 3.6/kwh (about 0.12/kwh) is used to calculate the electricity consumption cost.

(5) The wholesale price for the compost produced by Cases 1 and 2 is NT$ 4000/tonne and NT$ 3040/tonne, respectively, while Case 3 adopts a direct sale to the end user (farmers) at the price of NT$ 9270/tonne. In contrast, the compost produced by Cases 4–6 are not sold, but presented as a gift to farmers who have engaged in waste recycling. The market value of the compost produced by government affiliated units (Cases 4–6) is assumed to be NT$ 2000/tonne since no market exists for their products.

(6) The environmental impact including the greenhouse gas (GHG) emissions and waste water disposal resulting from the composting process is neglected.

4. Cost/Benefit Analysis of Food Waste Composting

The cost/benefit analysis of compost production among these cases are obtained and listed in Table 2. The cost of the produced compost ranges from NT$ 2897–23,117/tonne, depending on operating modes and capacities. Private firms have an average cost of NT$ 3908/tonne less than GACUs (NT$ 11,583/tonne). Table 2 also illustrates that the capacity of composting facilities makes a great influence on production costs. Higher output may lead to lower production costs. Among these cases, the cost of Case 6 is the highest. For each tonne of the produced compost, Case 6 has to bear the fixed cost of NT$ 14,046, which includes financial costs and depreciation costs for land, buildings, and machinery, and the variable cost of NT$ 9071.

Table 2. The production cost of compost.

Case	1	2	3	4	5	6
Output [a]	18,000	9600	850	1300	600	72
Designed capacity [a]	36,000	18,000	1800	3600	2880	540
Annual total cost [b]	68,734,000	27,929,936	4,256,945	6,633,333	3,917,667	1,864,433
fixed cost	28,920,000	4,725,536	1,410,940	1,713,333	1,670,667	1,011,333
variable cost	39,814,000	32,655,472	2,846,005	4,920,000	2,247,000	853,100
Unit total cost [c]	3819	2897	5008	5103	6529	23,117
fixed cost	1607	388	1660	1318	2784	14,046
variable cost	2212	2509	3348	3785	3745	9071
unit market price [c]	4000	3040	9270	3000	3000	3000
unit profit [c]	181	131	4262	(2103)	(3529)	(20,117)

[a] Unit: tonne/year; [b] Unit: NT$/year; [c] Unit: NT$/tonne.

The production process of these six case plants can be categorized into three levels: fully automatic, semi-automatic, and manual operation. Case 1 adopts a fully automatic process with a far larger production capacity; Case 2 and Case 4 adopt the semi-automatic process with a mechanical aeration process, and Case 3, Case 5 and Case 6 adopt the traditional method by using manual operation. Generally speaking, a plant with a more automatic process requires higher capital investment. The machinery for highly technical composting plants employed by Case 1 is expensive and should be imported, so it brings about higher unit fixed costs, and its cost is still almost the same as the average cost of the semi-automatic process, as shown in Figure 3.

The semi-automatic process with mechanical aeration adopted by Case 2 and Case 4 has the relative advantages of low machinery investment costs over Case 1. Among the process options, the capital investment cost for manual operation by the traditional composting method adopted by Cases 3, 5, and 6 are much lower and, thus, machinery maintenance costs and electricity consumption are significantly reduced. However, the process with manual operation requires more land and long times to produce the compost. Eventually, the unit cost operated by the manual process increases.

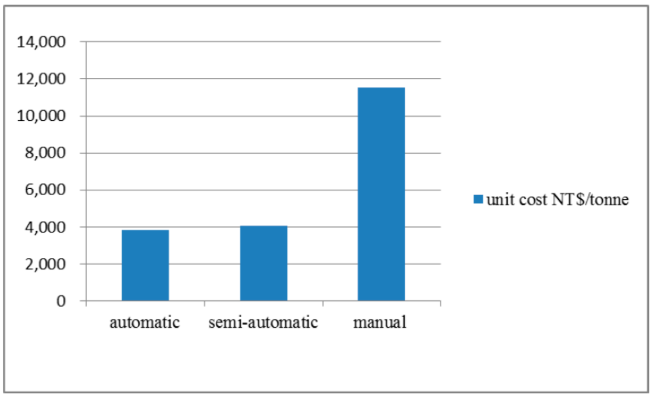

Figure 3. Cost of compost for different technologies.

Renkow and Rubin [23] examined 19 MSW composting facilities in the United States where automatic process is used, including windrow-based technologies and in-vessel technologies. They find that the cost of MSW composting is around $50 per ton and most of these 19 facilities cannot make a profit. Compared to the study of Renkow and Rubin [23], the cost of Case 1 is a little higher, while other facilities are much higher. The result in Table 2 may possibly lead to a conclusion that an automatic process or semi-automatic process may have higher production efficiencies and lower production costs. This result is consistent with certain previous studies. Couth and Trois [24] conduct a cost comparison for composting of MSW, finding that mechanically sorted and shredded MSW in turned windrow mechanical biological treatment (MBT) has been ranked higher than MSW in passively static aerated windrows, followed by shredded MSW in turned windrows. They suggest that mechanically sorted and shredded MSW in turned windrows is the favorite option according to the cost/benefit analysis. Meyer-Kohlstock et al. [25] evaluate the cost and benefit of composting based on a recent survey of some German composting plants. Some lead to stricter regulations on air quality, or a difficult building ground, or the selection of a complex technology which will increase investment and operating costs.

In consideration of the net profit for each unit Case 3 is ranked first, although its production cost is not the lowest. The net profit for Case 3 is NT$ 5321/tonne, much higher than the other two private firms due to its high price of final products. Case 3 employs a direct marketing method to avoid the distribution cost and, thus, the price reaches NT$ 9270/tonne. In contrast, the other two private firms (Case 1 and 2) sell their compost through wholesale systems with a wholesale price of NT$ 4000 and NT$ 3040 per tonne, respectively. Thus, Case 1 gains higher unit profit than Case 2, even though the production cost of Case 1 is higher. The payback period for each of the three private firms is 110, 55, and 13.6 years, respectively. The selling price of compost of these private firms varies greatly and makes a big influence on the net profit. This result implies that the marketing program for compost should be focused. Due to a too long payback period, a financial subsidy is a necessity for organic fertilizers to replace traditional mineral fertilizers.

The loss of all GACUs (Cases 4, 5, and 6) shown in Table 2 may be explained by the high production cost and low market value. The low sales revenue is not sufficient to support the composting operation for such a simple technology and existing building structures for GACUs. However, all of these GACUs are financially supported by Taiwan EPA for the purpose of demonstration. No market-oriented objective is established in these GACUs and, thus, no financial pressure or profit motives existent for these GACUs. Under such circumstances, all the 319 GACUs in Taiwan established under the national development program entitled “challenging the 2008 green industry-resources recycling, recovery and reuse” seem to fail to support the expansion of food waste recycling in the long run.

5. Discussion

The above results suggest that the compost producers have to enhance the market value of the organic compost and its competitiveness against mineral fertilizers. According to the Council of Agriculture [22], the market share of organic fertilizers is still very low, less than 10% of total fertilizer consumption. The low market share of organic compost may result from governmental policies. Currently, the Taiwan government offers subsidies for mineral fertilizers to the Taiwan Fertilizer Co. (TFC), the government-owned fertilizer producer of traditional mineral fertilizers for the stable supply of fertilizers to farmers. The high subsidy of NT$ 3000–12,000/tonne, depending on the type of fertilizers, increases the market competitiveness of mineral fertilizers. Table 3 demonstrates the retail price and composition of some types of selected mineral fertilizers and organic fertilizers. The price of mineral fertilizers ranges from NT$ 6.0/kg to NT$ 36/kg, about half of that of neighboring countries. For example, the retail price of TFC's urea is NT$ 10,000/tonne, much lower than NT$ 16,120/tonne in China, NT$ 21,850/tonne in Japan, and NT$ 23,300/tonne in Korea [22].

In contrast, the price of organic fertilizers ranges from NT$ 6.4–12/kg, still lower than that of mineral fertilizers. The low market value of organic fertilizers may be attributed to the low productivity of compost [26,27]. Some researchers suggest that combinations of organic materials and mineral fertilizers may improve nutrient efficiency and increase the crop yield [28]. The field study of Pinitpaitoon et al. [27] attempts to identify the appropriate ratio of the combination, finding that the application of mineral fertilizers yields the highest net profit, while the highest rate of compost without mineral fertilizers yields the greatest loss.

Currently, no direct subsidy is implemented for recycling food waste in Taiwan, while some other countries, like India, provide subsidies to the producer of MSW composts due to the benefit of compost to the crop and the soil. However, an indirect incentive mechanism has been used to encourage the adoption of organic fertilizers in Taiwan since 2008. An incentive amounting to NT$ 6000 is subsidized to the labor cost of farmers for organic fertilizer application for each hectare of field [29]. Furthermore, the Taiwan government also provides several technical services to farmers for free, including (1) testing of soil fertility; (2) the recommendation of fertilizer applications based on the soil fertility tests; and (3) crop fertilizer diagnosis. The technical support and the incentive mechanism have actually improved the soil productivity and the yield of crops, accompanied by the reduction in the consumption of mineral fertilizers. The consumption of mineral fertilizer per each hectare of field decreased from 1529 kg in 2007 to 1352 kg in 2014. The application of organic fertilizer can increase sales revenue of fruits by NT$ 23,000–97,000/hectare, and cost saving for rice crops by 20%–40% [29]. The data analysis provided by the Council of Agriculture [29] suggests that organic fertilizers (compost) may substitute for mineral fertilizers.

Table 3. Retail price of selected fertilizer produced by TFC, unit: NT$.

		Major Composition (%)				**Weight per Bag**	**Price (NT$)**
		N	**P**	**K**	**O.C.**		
Mineral fertilizer	KCl			60		40 kg	400
	$(NH_4)_2SO_4$	21				40 kg	240
	Urea	40				40 kg	400
	CaP_2O_5		18			40 kg	180
	K_2SO_4			50		40 kg	800
	TFC #1	26	13	13		10 kg	310
	TFC #4	14	28	14		10 kg	360
	TFC #6	5	18	18		10 kg	330
Organic fertilizer	Natural base	2.5	2.5	1.5	60	25	160
	Dingshin #2	5	2	2	62	20	240
	Dingshin #3	5.5	4.1	2.6	70	25	270

O.C.: content of organic matter.

According to the estimation of Taiwan's Council of Agriculture [22], each hectare of farmland requires 12 tonnes of fertilizers every year. Taiwan owns a total farmland of 870,000 hectares and, thus, the market demand for fertilizers may reach 10.44 million tonnes every year. If food waste recycled in 2014 is completely used for compost production, the compost produced can supply 7.78% of the total demand for fertilizers. Currently, MSW incineration has been employed as the major method for the final disposal of MSW in Taiwan. In practice, the operating cost for MSW incineration varies from one plant to another, depending on the installed capacity, the operation mode and other parameters [30]. According to the data issued by Environmental Protection Administration [1], the incineration cost is NT$ 2500/tonne of MSW, including the final ash disposal. Since the composting of food waste can save NT$ 2500 per tonne of food waste for the disposal of MSW through incineration, this paper suggests that a subsidy of NT$ 2500 per tonne of food waste to the compost producer may expand the market demand for the compost produced by food waste.

The result of this article confirms that composting is a proven technology for the treatment of food waste because of its simple process and easy operation. According to the regulation announced by the Council of Agriculture [31] in 2008 and revised in 2013, fertilizer producers has to declare the composition of fertilizer sold on the market, including (1) the content of principal components, such as nitrogen (N_2), phosphate (P_2O_5), potassium oxide (K_2O), and organic matter; (2) hazardous components, such as Arsenic (As), Mercury (Hg), Chromium (Cr), etc.; and (3) other requirements. The specification for compost should meet (1) the standard of principal components: organic matter: $\geq$50%, N_2: 0.6%–3.0%, P_2O_5: $\geq$0.3%, K_2O: $\leq$4.0%; (2) hazardous components: As: $\leq$25.0 mg/kg, Cd: $\leq$2.0 mg/kg, Cr: $\leq$150 mg/kg, Cu: $\leq$100 mg/kg, Hg: $\leq$1.0 mg/kg, Ni: $\leq$25.0 mg/kg, Pb: $\leq$150 mg/kg, and Zn: $\leq$250 mg/kg; and (3) other limits: H_2O (water): $\leq$40.0%, pH: 5.0–9.0, ratio of C/N: 10–25. The specification of the compost must be approved before production and the products on the market should be checked randomly to assure the compliance with the current regulation. In addition, biological composting may have relative advantages over other applications, including (1) the moderate quality level required for composting application; (2) the avoidance of odor release to the environment; (3) an increase in employment level for composting plants; and (4) reduced health risks. Hence, good waste composting may become a leading disposal among all applications in the future. In fact, Taiwan has set up strict targets to increase the food waste recycled. In 2003, Taiwan's national development program of "challenging the 2008 green industry-resources recycling, recovery and reuse" was effective and a budget was prepared to promote food waste recycling [1]. The food waste collecting system implemented in Taiwan has also been established and proved to be successful. Thus, such an effective system for food waste recycling is also a warranty of the constant and stable quality of raw material supply to the composting plants.

In addition to composting, the food waste also can be used as a raw material for the production of biogas that is generally generated in the composting process. Several studies focus on the technology and economic evaluation on the production of biogas from various sources [32–36], the investigation on the process improvement of biogas production [37,38], the assessment of the potential for biogas plants in comparison with wind power plants [39]. About 30% of the organic matter in the MSW composition is seen as a good potential source for biogas production [34] and, thus, it is possible to convert MSW into biogas as Taiwan's MSW contains organic matter ranging between 30%–40% (see Figure 1).

6. Conclusions

In this paper, the cost/benefit analysis for the assessment of food waste composting are presented. In particular, the role of the production process and production capacity in affecting the costs of compost is highlighted. The financial cost of machinery investment plays the most important role in affecting unit production costs. Small scale production may be inefficient in production, leading to a cost increase. On the other hand, the result finds that few facilities can gain profits due to small scale and low market value. The produced compost is greatly distinguished by marketing activities among the composting plants. The trade-off between the market value of compost and the financial cost of machinery investment should be carefully analyzed to select an appropriate production capacity and process.

Since food waste recycling provides a direct benefit of incineration cost saving, this paper also suggests that a financial subsidy should be directly given to compost producers to expand the market demand and to provide an incentive for food waste recycling. As the addition of compost can improve soil physical properties and increase both water holding capacity and the supply of essential nutrients [40–43], the potential to substitute the traditional mineral fertilizer is great enough. In addition to the subsidy, a promotion program is also needed to expand the market demand as most farmers are still not aware of the relative advantages of biological compost over mineral fertilizers. In order to guarantee the good quality of compost produced in the market, product standards should be regulated. The technical analysis between organic fertilizers of compost and mineral fertilizers should be conducted and released to the farmers.

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