The 6th International Symposium on East Asian Resources Recycling Technology
October 23 - 25, 2001, Gyeongju (慶州), Korea
ISBN: 89-952527-0-7 93530

A Statistical Analysis of Recycling Cost for Waste Home Appliances

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On July 5, 1997, Environmental Protection Administration of Taiwan publicized the recycling regulation of waste home appliances that include four items, namely, television, refrigerator, washing machine, and air conditioner. It is believed that this regulation pioneers the law enforcement of waste home appliances in the world. To comply with the policy, several contemporary waste disposal plants specialized in waste home appliances were established according to a follow-up technical specification on the waste treatment facilities and methodology. Therefore, the traditional dismantling facilities were substituted and waste collection routes were altered as well accordingly. This study investigates the collection and recycling costs of waste home appliances in accordance with these newly established routes and facilities, respectively. Cost survey was conducted among collectors and recycling plants of waste home appliances; consequently, the collection and recycling costs were analyzed, correspondingly. Results show that the recycling costs of waste home appliances were much higher than that of other waste items. Since the market share of recycled materials is lacking, these waste recycling plants of home appliances can only survive under the subsidy of EPA in Taiwan. Due to some arduous problems, the subsidiary system has already caused serious financial unbalance for a foundation under EPA of Taiwan, which associated with waste recycling in Taiwan.
Keywords: waste home appliances, collection cost, recycling cost, waste recycling

Introduction

On July 5, 1997, Environmental Protection Administration of Taiwan publicized the recycling regulation of waste home appliances that include four items, namely, television, refrigerator, washing machine, and air conditioner. It is believed that this regulation pioneers the law enforcement of waste home appliances in the world. Under the current 4-in-1 recycling policy, manufacturers and importers of home appliances have to pay a collection/recycling fee for each kind of the four items to the Resource Recovery Management Fund Commission (RRMFC) based upon the rate approved by EPA. Collectors and recycling plants receive subsidy and other relevant expenses such as refund from RRMFC according to the collected and treated amounts audited by an independent auditing organization. The subsidy and other expenses are the major expenditure of RRMFC [1,2].

Since there were no proper treatment facilities for these waste home appliances at the initial stage, RRMFC has conducted the selection for temporary storage sites [3]. It has been very successful in managing these wastes at this period; however, the cost of temporary storage was catching up. In coordinate with the recycling policy of EPA, six recycling plants specialized in the treatment of waste home appliances have been constructed during 1998 to 1999 [4]. Because of higher standards, the initial cost of these plants is much higher than that of other kind of recycling business. Since the market share of recycled materials is lacking, recyclers can survive only due to the subsidy mechanism; about 75% of operational income of recycling plant comes from subsidy. In order to release the pressure from storage cost, recyclers were asked by EPA to accelerate the recycling treatment by two shifts, so that all the stored waste home appliances have been dismantled and recycling treated within one year. Since the approved subsidy of recycling treatment is high because of higher initial cost and standards, RRMFC has serious financial unbalance problem in managing the waste home appliances. Whereas, the number of collected air conditioner, which contents polluted coolant, is far few compared with other three items because it has higher recycled values. Most of waste air conditioners have been sold at first place to the traditional dismantlers who have not well equipped especially in the recovering CFCs and lubricants. The spray of coolant during above operation by traditional dismantlers has always been the major concern of environmental protection groups [5].

On the other hand, the collected amount of waste home appliances are not growing after these stored wastes have been processed/treated; recycling plants start to concern the steady incoming of wastes. At the mean time, recyclers raise the sale prize of wastes to recycling plants, so that the collection route has an impediment in the recycling path. All these problems lead to some arguments on the collection/recycling fees of manufacturers/importers as well as the collection and recycling subsidies of collectors and recyclers, respectively, of these four waste items. The objective of this study is to estimate collection and recycling costs based upon the sampling survey and statistical analysis to provide helpful base for amending collection/recycling fees and subsidies of these four kinds of waste home appliances. Once the precise costs of collection/recycling are obtained, the fees and subsidies are reasonable and acceptable for both manufacturers/imports to pay and collectors/recyclers to receive, respectively.

In this study, the averaged collection costs of television, refrigerator, washing machine, and air conditioner are respectively NT$122, 210, 134, and 165 per each waste machine during year 2000; as the recycling plants, the averaged recycling costs are NT$255, 438, 277, and 343

each, respectively. Benefits of recycled materials depend very much on the treatment technology and plant managing skill of each recycling plant. The averaged benefits of television, refrigerator, washing machine, and air conditioner are respectively NT$22, 180, 104, and 269 each. Sale prizes of these recycled materials are varying within all six plants, so that standard deviations of these benefits are very large as well.

Methodology

Collection and recycling cost estimations of waste home appliances are mainly based upon the sampling survey, which includes collection routes, recycling/recovery treatment, and annual amount of wastes, thereafter, statistical analyses are conducted by using these survey results. Sampling design of survey and economical/statistical analyses of collection/recycling costs are explained in the following sub-sections [5,6].

Sample Design

The aim of present survey is to estimate the collection and recycling costs of waste home appliances in Taiwan. The period of study is year 2000. Target population includes all of collectors and recycling plants of waste home appliances in Taiwan, which consists of 1,141 collectors and 6 recycling plants. Systematic sampling combined with stratification is used to select a probability sample of collectors, whereas, the corresponding estimator is used to estimate the collection cost. A fundamental principle of sampling survey theory is that if sampling units can be classified into strata that are internally homogeneous with respect to the variables to be estimated, and independent sub-samples are selected from each stratum, then the variance of overall estimators may be reduced. Due to effect of socioeconomic characteristics and environmental policy of local government on the waste recycling system, collectors were stratified based on counties. It is commonly believed that the collection cost varies considerably with different counties. Thus there are 23 strata in all. From each county, a systematic sample was selected and the selected collectors were interviewed to obtain related collection costs of waste home appliances. Five recycling plants already have permission to process/recover the waste home appliances during the survey period; they are investigated to obtain the recycling cost. Face to face interviews are conducted to collect data in order to increase the precision of estimation and reduce the non-response rate.

Estimation of Collection and Recycling Costs

The estimation of collection cost in this paper will concern about probability distribution, outliers, and scales of collectors simultaneously. The collectors in Taiwan have very different scales ranging from very small to very large. The collection cost may not be normally distributed. It is necessary to properly manipulate the outliers. Therefore, to increase the precision of estimation, a process was conducted to estimate collection cost for each county with the following steps [5,6]:

1. Use Kolmogorov-Smirnov test (K-S test) to verify the normality of the data.
2. If the data is normally distributed, then calculate the mean as an estimate of collection cost for that county.
3. If the data is not normally distributed, then conduct following steps to obtain the estimate.
   (i) For data with symmetric and left-skewed distribution, use α-Winsorized mean to adjust its distribution by choosing a proper α-value and obtain the mean for the adjusted data.
   (ii) For the data with right-skewed distribution, fit the data with Gamma or Lognormal distribution and obtain the mean of probability distribution.

The following estimation formula was used with the stratification of the sampling design to obtain the higher precision of estimation. The unbiased estimator of population mean is written as [7]

$$\bar{y}_{st} = (\sum_{N=1}^{h} N_h \cdot \bar{y}_h) / N \qquad (1)$$

where

$\bar{y}_{st}$ = estimated mean of collection cost

N = total number of collectors in population

N_h = total number of collectors in stratum h

$\bar{y}_h$ = sample mean of collection cost in stratum h

In equation (1), $\bar{y}_h$ was obtained through the estimation steps in previous descriptions. For stratified random sampling, the unbiased estimator of variance of estimated $\bar{y}_{st}$ is

$$\hat{V}(\bar{y}_{st}) = \sum_{N=1}^{h} [(N_h^2 / N^2) \cdot ((N_h - n_h)/n_h) \cdot (s_h^2 / n_h)] \qquad (2)$$

where

$\hat{V}(\bar{y}_{st})$ = estimated variance of $\bar{y}_{st}$

n_h = number of sampled collectors in stratum h

s_h^2 = sample variance of collection cost in stratum h

To recycle waste home appliances, collectors/recycling plants incur two major types of costs, which are capital costs as well as operating and maintenance (O&M) costs. Capital costs are one-time expenditures including equipments (e.g., vehicles, storage containers, conveyors, crushers, balers, *etc.*), land, building construction, and plant improvements. Capital costs can be accounted as one-time expenses or amortized over the lifetime of the equipment. Annualized capital costs could present annual depreciation of capital investment. Basically, capital costs have been converted into annual costs by assuming a 7-year amortization period for collection equipments and 9-year amortization period for recycling/recovery equipments. Annual O&M costs are ongoing expenses that include items such as equipment leasing and maintenance, utilities, labor, administrative expenses, licenses, supplies, insurance, residue disposal, marketing

fees, contract fees, education/publicity program. In this study, O&M costs are broken down into three basic categories, *i.e.*, labor, transportation, and administration for collectors, whereas four basic categories, *i.e.*, labor, equipment maintenance, residue disposal, and administration for recycling plants. Most O&M costs for recycling plants vary with the amount of processed waste home appliances and labor hours spent. Some O&M costs such as insurance fees and education/publicity costs remain fixed despite the amount of waste processed.

Therefore, the gross collection cost of waste home appliances in the base year of study includes annualized collection capital cost, labor cost, transportation cost and administration cost. The unit collection cost reflects annual cost of collection incurred in the base year of study divided by the annual amount of collected waste home appliances. The gross recycling cost of waste home appliances in the base year of study includes annualized recycling capital cost, labor cost, maintenance cost of equipment, administration cost, and residue disposal cost. The unit recycling cost reflects annual processing/recovering cost incurred in the base year of study divided by the annual amount processed/recovered. Recycling revenue is also calculated by the sale income of recycled materials. By subtracting recycling revenue from total recycling cost, the net cost of recycling is obtained, which provides the base of subsidy for recycling plants. Better processing/recovering technologies and equipments might increase the revenue and reduce the residue disposal cost as well.

Statistical Analysis

Waste home appliances discarded by consumers were collected and transported to recycling plants or dismantling shops *via* various collection/recycling routes as shown in Figure1. Usually the collectors in the rear of collection route are large-scale collectors who purchase waste home appliances from consumers, collection points, home appliance distributors, municipal solid waste cleaning crews, and the collectors in the front of collection route with different prices. Recycling plants have class-A treatment plant permit of waste home appliances from EPA, while the dismantling shops are traditional dismantlers without treatment permit [8]. Recycling plants could receive recycling subsidy from RRMFC for processing/recovering waste home appliances, but dismantling shops won't have any subsidy from RRMFC. The collectors will receive collection subsidy from RRMFC if they ship the collected waste home appliances to recycling plants, but they do not get any subsidy for sending these goods to dismantling shop. The current collection/recycling fees and subsidies implemented from January 1, 2001 are shown in Table 1 (see [2], [5] and [9] for the details). The collection/recycling fees charged on importers and manufacturers are the major fund source of RRMFC, while the subsidies of collection and recycling paid to collectors and recycling plants, respectively are the major expenditures of RRMFC. If the price offered by dismantling shops is much higher than the collection subsidy of RRMFC, the collected waste home appliances will be sent to dismantling shop.

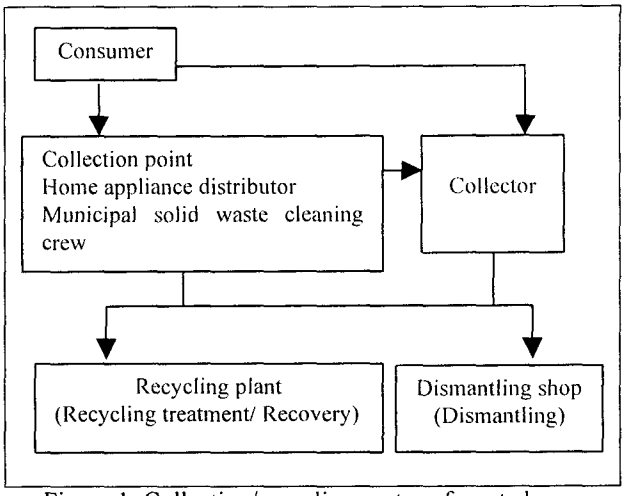

Figure 1: Collection/recycling routes of waste home appliances

Table 1: Current collection/recycling fees and subsidies of waste home appliances

Unit: NT$/unit

	TV set		Refrigerator		Washing machine	Air Condi-tioner
	Big size	Small size	Big size	Small size		
Collection/ recycling fee	420	270	680	440	360	290
Collection subsidy	170		365		225	315
Recycling subsidy	280		370		190	120

Notes: Collection subsidy includes subsidies for collection, management of collection point, management of collector, transportation fee of collection, and transportation fee from collector to recycling plant for general area. Recycling subsidy includes process/recover subsidy only for recycling plant.

Source: RRFMC, EPA, Taiwan.

Tables 2 and 3 represent the results obtained from sampling survey. The quantities for domestic use of TV, refrigerator, washing machine, and air conditioner are shown in Table 2, where the amounts taken into account of paying the collection/recycling fees are 1,144, 581, 515, and 1,141 thousand units, respectively in 2000. The numbers of domestic generated waste of TV, refrigerator, washing machine, and air conditioner are estimated about 636, 580, 449, and 953 thousand units, respectively in 2000. The quantities for these four home appliances collected in 2000 and certified by auditor organization, which could receive collection subsidy from RRMFC, are 425, 189, 286, and 86 thousand units respectively. The certified quantities of recycling are the waste home appliances processed/recovered by recycling plants and certified by auditor organization in 2000. Table 2 revealed that the certified quantities of recycling are much larger than that of the collection certified. The difference of these two quantities is the stocked amounts that were collected in the previous year but recycled in 2000. In

2000, the collection rate of home appliances based on the certified collection quantities divided by domestic waste generated quantities are around 67%, 33%, 64%, and 9% for TV, refrigerator, washing machine, and air conditioner, respectively. The collection rate of air conditioner based on the certified quantities is much lower than that of others, because most of waste air conditioners were sold to dismantling shops. Table 3 shows that high percentage of collected waste air conditioners have been sent to dismantling shops. The price offered by dismantling shops is much higher than the collection subsidy of RRMFC. The recycling/recovery rate for TV and washing machine are far beyond 100%, but only 13% for air conditioner. The high recycling/recovery rate in 2000 seriously caused deficit of recycling management fund of waste home appliances.

Table 2: Collection and recycling/recovery rates of waste home appliances in year 2000

Unit: 1,000

	TV set	Refrigerator	Washing machine	Air Conditioner
Quantities of domestic use	1,144	581	515	1,141
Quantities of domestic waste generated	636	580	449	953
Certified quantities of collection	425	189	286	86
Certified quantities of recycling/recovery	1,053	577	641	127
Collection rate	67%	33%	64%	9%
Recycling/ recovery rate	165%	99%	143%	13%

Notes: The quantities of domestic waste generated exclude the quantities exported and reused in 2nd hand market. The waste generated are calculated based on the data from [1] and [10].

Table 3: Where the collected waste home appliances go

Unit: %

	TV set	Refrigerator	Washing machine	Air Conditioner
Recycling plant	87.49	96.06	98.65	67.34
Dismantling shop	12.51	3.93	1.35	32.66

Notes: Recycling plants have class-A treatment plant permit of waste home appliances from EPA; dismantling shops are traditional dismantlers without treatment permit.

Table 4 shows the collection and recycling costs of waste home appliances. The collection cost covers all the expenses that collectors collect waste home appliances from consumers and finally transport them to the recycling plant. Basically the major costs include annualized collection capital cost and O&M cost (e.g., labor cost, transportation cost, and administration cost). Average collection cost based on the survey of 124 sampled collectors as shown in Table 4 is NT$122 per waste TV set, 210 per waste refrigerator, 134 per waste washing machine, and 165 per waste air conditioner. The collection costs are varied *via* different collection routes. The cheapest collection cost is *via* the route that the waste home appliance comes from consumer *via* home appliance distributor and directly transported to recycling plant without *via* collectors. The home appliance distributors are part time collectors of waste home appliances who are playing an important role in the recycling route. Currently, most of home appliance distributors send the take-back waste home appliances to the nearby collectors because the distributors don't have enough storage space for the waste home appliances. Therefore collectors act like transportation points where waste home appliances are temporary stored and transported to recycling plant whenever the collection amounts fulfill the transportation requirement. The collection subsidy of collectors depends on the audited amount at the recycling plant where waste home appliances be shipped to. Nevertheless, the collectors could ask some extra benefits from the recycling plant besides the collection subsidy from RRMFC. The behavior of collectors has already caused serious impediment in the collection route. Moreover, due to their higher recycled values, most of waste air conditioners have been sold at first place to the traditional dismantlers who have not well equipped especially in the recovering CFCs and lubricants. The spray of coolant during above operation by traditional dismantlers has always been the major concern of environmental protection groups.

Table 4: Collection and recycling costs of waste home appliances in year 2000

Unit: NT$/unit

Items	TV set	Refrigerator	Washing machine	Air Conditioner
Collection Cost	122	210	134	165
(Standard error)	(25)	(43)	(28)	(34)
Recycling Cost	255	438	277	343
(Standard deviation)	(41)	(84)	(50)	(84)
Residue Disposal Cost	66	50	65	50
(Standard deviation)	(16)	(38)	(18)	(47)
Revenue	22	180	104	269
(Standard deviation)	(7)	(30)	(30)	(74)
Net recycling cost	233	257	173	74
(Standard deviation)	(40)	(86)	(65)	(117)

Notes: The Recycling Cost includes residue disposal cost.

The recycling cost covers all the expenses that recycling plants process/recover the collected waste home appliances. That represents recycling plants' actual intermediate processing expenses which include annualized recycling capital cost, O&M cost (e.g., labor cost, maintenance cost of equipment, residue disposal cost, and administration cost). It was found that the average recycling costs of TV set, refrigerator, washing machine, and air conditioner are NT$255, 438, 277, and 343 per unit, respectively based on the survey of five operating recycling plants in year 2000. Residue disposal cost as shown in Table 4 represents the cost of final disposed waste. The residue disposal cost is calculated

based on the contract of recycling plant and waste disposal agent. Most of final waste residues are land filled or incinerated; some small portion of final residues is temporary stored and waiting for further process/treatment. The waste residues include cone tube glass, panel glass, and fluorescent powder from the CRT of waste TV set; CFCs, mineral oil, and PUR foaming agent from waste refrigerator; CFCs and mineral oil from air conditioner; electronic scraps from all these four waste home appliances. In accordance with the survey, the residue disposal cost of TV set, refrigerator, washing machine, and air conditioner are NT$66, 50, 65, and 50 per unit, respectively. The residue disposal cost with large standard deviation reveals differential recycling technology of the recycling plant. The recycling plant with higher level of recycling/recovery technology could gather less waste residue.

In Table 4 also shows revenue per unit waste treated, which represents the total revenue received by the recycling plants from the sales of recycled materials divided by the total units of recycled/recovered home appliances. The revenue of recycled material generally includes metals such as steel, copper, and aluminum, as well as plastic materials recovered from these four waste home appliances; coolant and compressor recovered from waste refrigerator and air conditioner; and motor recovered from waste washing machine. The revenue of recycling/recovering a waste TV, refrigerator, washing machine, and air conditioner are NT$22, 180, 104, and 269 per unit, respectively shown in Table 4. The revenue of recycled material also highly depends on the level of recycling technology of recycling plant, the domestic economic condition, and international trading condition.

The net recycling cost in Table 4 is obtained by subtracting recycling revenue from total recycling cost, which provides the base of subsidy for recycling plants. The net recycling costs of waste TV set, refrigerator, washing machine, and air conditioner are NT$233, 257, 173, and 74 per unit, respectively. The net recycling cost of waste air conditioner ranged from minimum NT$-61 to maximum NT$256 significantly reflects the level of recycling technology in response to the recycling equipment. The positive net recycling cost implies that recycling plants of waste home appliances can only survive under the subsidy of EPA in Taiwan.

Obviously, the lower the residue disposal costs are, the higher the revenues of recycled material are. Enhancing recycling technology to increase the quality of recycled material, in fact, increases the demand for recycled materials and hence reduces disposal requirements. That is the better way to reduce the net recycling cost. Improved market conditions for recyclables, resulting from stimulated demand for recycled goods, will also lower net recycling costs. Yet, recycling plants don't have to rely on the subsidy system. Eliminating waste collection and recycling costs are driving the cost-effectiveness of recycling.

Policy Implications and Conclusion

This paper presents estimated collection and recycling costs of waste home appliances based on a sampling survey. By choosing a proper sampling technique and a good estimator, the precision and accuracy of estimation are obtained. Results show that the recycling costs of waste home appliances were much higher than that of other waste items. Since the market share of recycled materials is lacking, these waste recycling plants of home appliances can only survive under the subsidy of EPA in Taiwan. Moreover, in order to release the pressure from storage cost, recycling plants were asked by EPA to accelerate the recycling treatment by two shifts, which caused serious deficit of foundation associated with waste recycling of home appliances in Taiwan. Most of waste air conditioners have been sold at first place to the traditional dismantlers who have not well equipped especially in the recovering CFCs and lubricants. The spray of coolant during above operation by traditional dismantlers has always been the major concern of environmental protection groups. Additionally, the collected amount of waste home appliances are not growing after these stored wastes have been treated; recycling plants start to concern the steady incoming of wastes. At the mean time, collectors raise the sale prize of wastes to recycling plant, so that the collection route has an impediment in the recycling path. All these problems lead to some arguments on the collection/recycling fees of manufacturers/importers as well as the collection and recycling subsidies of collectors and recyclers, respectively, of these four waste items. The collection and recycling costs estimated in this paper provide the base of amending collection/recycling fees and subsidies of these four kinds of waste home appliances.

Results also provide insight visions into the decision-making process by which recycling equipments were selected. Such insights may provide useful indications of how to improve future decision-making regarding the recycling of waste home appliances. How to establish a cost-effective recycling system to lower the recycling cost and enhance the recycling technologies to reduce the recycling cost is an urgent issue. In general, it was found that how to provide incentives for reducing illegal disposal and in the mean time increasing the collection and recycling rates might be difficult to administer. Enhancing recycling technology to increase the quality of recycled material, in fact, increases the demand for recycled materials and hence reduces disposal requirements. In addition, that may raise prices of recycled materials, an outcome might be desired by collectors seeking to increase their collection rates. Of course, the encouragement of using recycled material instead of virgin material is an alternative option to increase recycling rate.

Nomenclature

The following definitions are applied to this paper only and not meant to represent industry-wide.

Annualized Capital Costs — Capital costs have been converted into annual costs by assuming a 7-year amortization period for collection equipments and 9-year amortization period for processing/recovering equipments.
Base Year of Study — The 12 months period over which amounts, costs, and other data apply. Quantities and cost data are reported on an annual basis and mostly for the calendar year 2000.
Collection Capital Costs — Costs of acquiring equipments used to collect recyclable waste home appliances.
Recycling Capital Costs — Costs of acquiring equipments used to process/recover recyclable waste home appliances.
Disposed Waste — Residues from recycling plant are in store for further treatment, land filled or incinerated.
Generated Waste — Sum of waste recycled and waste disposed.
Intermediate Processing — Preparing collected recyclable materials for the end-use manufacturing. Typical processes include sorting, contaminant removal, and crushing or baling for waste home appliance recovery.
Operating and Maintenance (O&M) Costs — Ongoing expenses that include items such as equipment leasing and maintenance, utilities, labor, administrative expensed, licenses, supplies, insurance, residue disposal, marketing fees, contract fees, and education/publicity programs.
Collected Waste — Discarded home appliances collected for recycling.
Recycled Waste — Discarded home appliances processed/recovered for reuse and/or processing into recycled materials or new products.
Recycling — Processing/recovering discarded home appliances for reuse and/or processing into recycled materials or new products.
Collection Rate — the waste home appliances collected for recycling (generally including any product rejected during processing) divided by the waste generated.
Recycling/recovery Rate — the waste home appliances processed/recovered divided by the waste home appliances generated.

Acknowledgments

Funding of this research by Environmental Protection Administration of Taiwan under grant No. EPA-90-HA31-03-060 is very much appreciated.

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