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A Study on the Assessment of Management Frameworks for Waste Electronic Home Appliances

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Serious adverse impacts on the environment and human health from the recycling and disposal of electronic waste have occurred in the past and continue to occur in China today, due to the lack of a national management strategy. With aiming to support the management strategy development, a study was carried out to plan and quantitatively evaluate the optional management frameworks for the selected five main types of large electronic home appliances in Beijing, the capital city and a typically big municipality in China. This paper outlined the main findings yielded from the series of assessment studies which started from the generation amount prediction and material flow analysis of the used electronic appliances, planning and optimization of the collection & transportation frameworks and ended at the economic evaluation of the optional recycling processes for the waste appliances. Although the revenue could be expected from the result of isolated evaluation of the recycling processes, the entire system will be economically unavailable if the used appliances are still collected from the owners at current prices. The traditional understanding of householders on the values of their used appliances should be changed in Beijing and China as a whole. Establishment of a formal collection system that could take back the used appliances at lower prices (less than 40% of the current level) is the key for the construction of a formal management framework with sustainability.

Keywords: *Waste electronic home appliances, Management framework, Assessment, Beijing, China*

1. Introduction

Electronic waste (hereinafter referred as e-waste) has globally attained importance in last decade. The production of electrical and electronic equipments is one of the fastest growing sectors along with the shift from an industrial society to an information society. Accordingly, the amount of e-waste keeps increasing very fast, at an expected rate of at least 3% to 5% per year in Europe as an example *(Cui et al. 2003)*. More than 10 countries/regions have set up regulations and infrastructure systems for e-waste management. Nearly all of them are economic developed such as EU member countries, Japan and North America. There are some differences between these established management systems due to the interpretation of the principle of extended producer responsibilities (EPR) *(Jofre et al. 2005)*.

The e-waste recycling system in developing economies such as China and India are quite similar but largely unorganized *(Li et al. 2004)*. The popular existing informal recycling processes caused serious damage to local ecosystem and human health. Low cost of the informal backyard recycling is a strong force to drive the illegal shipments of e-waste from industrialized countries to developing economies. The earlier establishment of a formal management system through legislative and infrastructure development in developing economies is an effective solution for e-waste from global perspective.

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An examination of Chinese fledgling e-waste management status shows that attempts to regulate and industrialize the recycling industry are facing a major challenge in terms of financing and collecting *(Liu et al. 2006)*. The pilot programs as well as newly established facilities are finding that it is difficult to compete with unregulated informal sectors. Informal collectors and second-hand appliances dealers remove the used products from the stream before formal recycling companies can obtain them, and divert them to informal processing workshops in poorer regions. The informal e-waste collecting and recycling processes must be regulated by construction and enforcement of legislations as soon as possible. The draft and approval of the management ordinance prepared by NDRC (National Development and Reform Commission) seems slow due to the difficulties to quantitatively define the EPR. This study is aiming to support the legislation formulation by estimating and more precisely predicting the amount of e-waste that is likely to be generated, and then quantitatively evaluating the cost and environmental impacts of the optional management frameworks from the vision of the life cycle of the generated e-waste.

2. Boundary and methodologies of the study

This study was carried out at large municipal level due to the obvious gap of economic and social development between urban and rural areas in China. Urban areas have much higher priority on the issue of e-waste management, especially in big municipalities which have high population densities. Urban region of Beijing, the capital city of China, was selected as the geographic boundary of this study due to the implementation feasibility. Five main types of large electronic home appliances (EHA) (TV set, refrigerator, air conditioner, washing machine and personal computer) were selected as the targets for this study since they have been listed in the management category of Chinese draft ordinance at the first stage. Additionally, the study was limited to the waste appliances generated from the households and excluded those from other sources as business offices because of data availability. Fig 1 indicated the entire boundary of this study. The materials from the point where EHA becomes the used product until the point where the fractions result from the various sorting, dismantling and recycling processes were examined in this study.

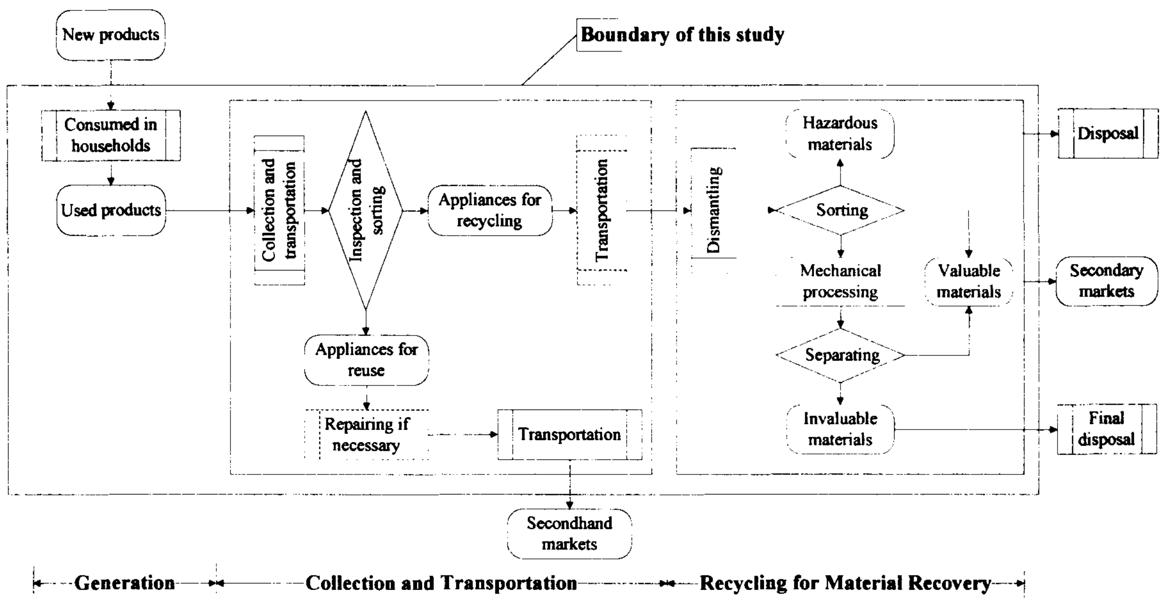

Fig 1: Boundary of the study.

A combined approach by using material flow analysis (MFA), linear programming (LP) and simplified waste life cycle assessment (WLCA) was applied in this study. MFA was used to quantify yearly amount of the used appliances waiting to be collected after estimating and predicting the total generation amount. LP models were developed for each of the possible collection and transportation frameworks. A simplified WLCA was added to clarify the appliances entering the recycling facilities and the leaving materials. A WLCA compatible financial waste life cycle costing (WLCC) was used for the economic evaluation of the optional recycling processes.

3. Results and discussions

3.1 Estimation and prediction of annual obsolete amount of EHA

The 'Market supply method', which is one of the three typical methods for the estimation of the possible quantities of e-waste explained by (*Lohse et al 1998)*, was used in this study. Fig 2 outlines the procedures of the annual obsolete amount estimation and prediction of electronic appliances from households. Annual sales amount (S_{t-i}) and the corresponding yearly obsolete ratio ($f(y)$) of the product are used for the calculation of obsolete amount in the t-th year (O_t). Statistical data on the average household possession amount ($\overline{P}_{t-i}$), sales amount (S_{t-i}), population and number of households (NH_{t-i}) are available in urban Beijing. The yearly obsolete ratio is calculated from a questionnaire survey data. Statistical data on the average amount of household possession was used to predict the possession amount in the future by regression. Then the sales amount in the t-th year can be calculated by using the relationship of possession amount, sales amount and obsolete amount in that year. The annual obsolete amount from the t-th year can be achieved by repeating the calculation.

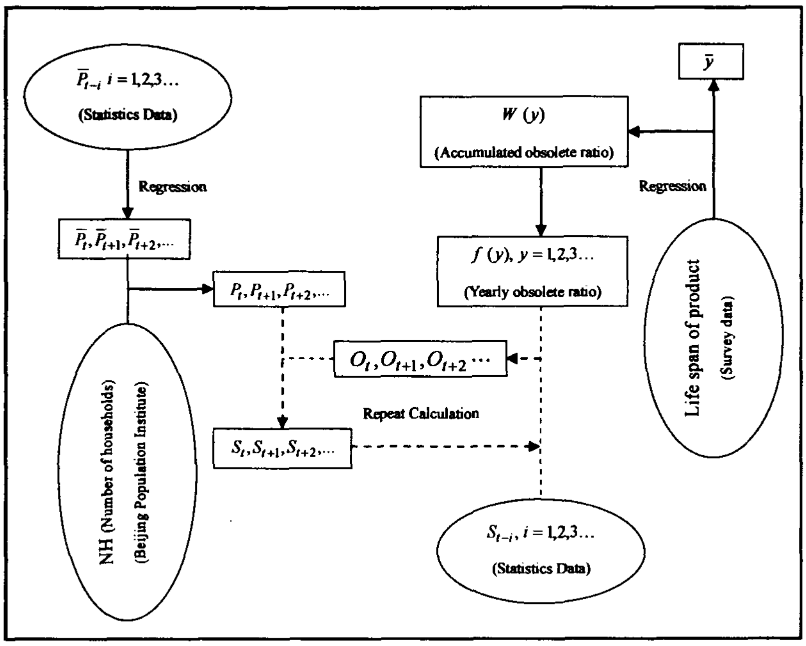

Fig 2: Procedures for the obsolete amount estimation and prediction.

Fig 3 shows the results of the total obsolete amount calculation. The total obsolete amount of color TVs, refrigerators and washing machines will increase slightly due to the urban population expanding even though their average possession amounts have nearly reached saturation. The obsolete amounts for personal computers and air conditioners will increase greatly in the next 5 years. The total obsolete amount of the five kinds of appliances in 2005 was 885,354 units. It is estimated that this number will increase to approximately 1,750,000 units by 2010, 2,310,000 units by 2015 and will reach approximate 2,820,000 units by 2020. Using the average weights provided by the producer, the total obsolete weight of the five kinds of appliances was 30,171.3 tonnes (3.5 kg/ capita) in 2005. It is estimated that this number will be 56,500 tonnes (5.86 kg/ capita) by 2010, 74,500 tonnes (6.93 kg/capita) by 2015 and will reach 92,000 tonnes (7.78 kg/capita) by 2020.

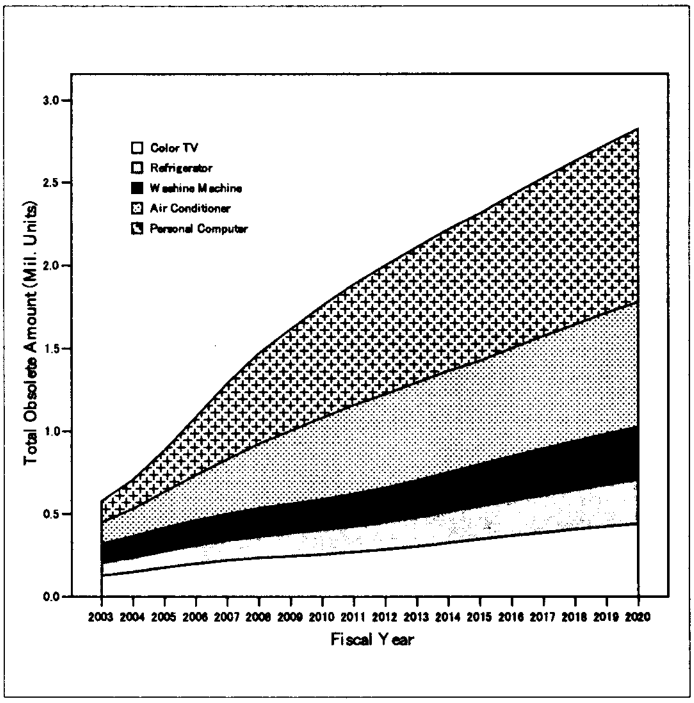

Fig 3: Annual obsolete amount of main electronic appliances from Beijing urban households in next 15 years.

3.2 Material flow analysis of the obsolete appliances

The method developed at Carnegie Mellon University *(Matthew 1997)* was used for the material flow analysis in this study. The reuse and storage parameters of obsolete appliances were included which in reality would delay their entry into the waste stream.

The results of the analysis of material flow of obsolete appliances are shown in Fig 4. Nearly 70% of the total obsolete amount needs to be collected for possible recycling by retailers, private individual collectors or other channels such as permanent collection stations set up by the municipalities, and repairing shops. About 20% of them will be reused directly by reassignment or donation. 7% will be stored in the houses of the original owners. 4% may be discarded directly to the municipal solid waste collection sites and collected by that route. This indicates that most of the obsolete appliances in Beijing could be collected for possible recycling if convenient services are available. Few households would like to store their obsolete appliances in their houses because of the limited living spaces. Few people would like to discard their end-of-life appliances directly because most owners traditionally understand that there remain value of these used products.

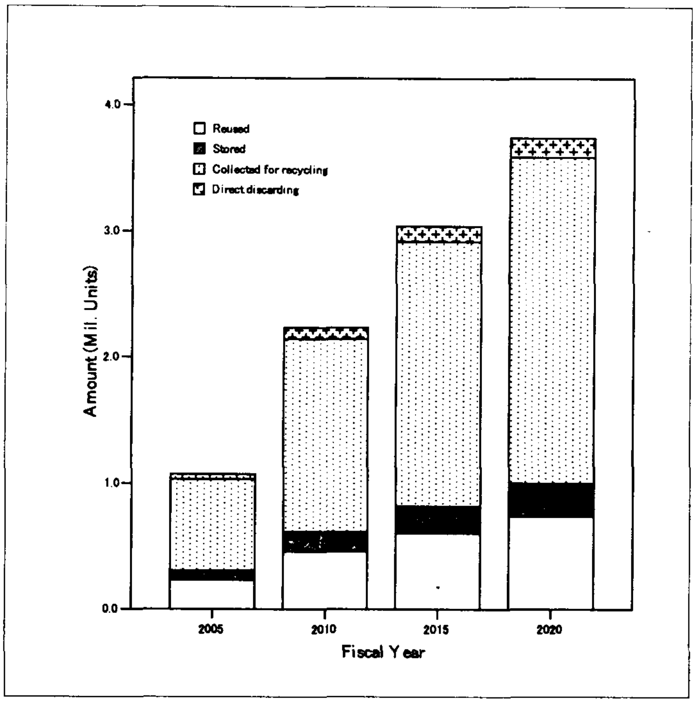

Fig 4 : Material flow analysis results of obsolete electronic appliances from Beijing urban households.

3.3 Planning and evaluation of the collection and transportation frameworks

Current status of waste EHA collection was surveyed and made clear. Two optional frameworks of using or not using the intermediate transfer stations planned for recyclable resources were optimized and compared. The total transportation loads (TTL) and average transportation distance (ATD) in the next 15 years were predicted based on the result of generation amount estimation. Average oil consumption (AOC) of and the pollutant emissions from the transportation vehicles were calculated. Current cost for the collection and transportation was also estimated.

3.3.1 Current status

Fig 5 indicates the current status of used EHA collection and transportation in Beijing. The information originated from an onsite survey implemented in Dec of 2005.The 5 main kinds of used electronic appliances from the households were collected via 5 channels. The individual private peddlers collected the most (about 75~80%) due to the convenient service and attractive price they provided to the final owners. Retailers collected about 15~20% of the total when they delivered the new purchased appliances to the consumers. In most cases, the collection of used electronic appliances by retailers had the purpose for sales promotion. Permanent collection points for recyclable resources collecting in residential communities played a limited role. Repairing shops and house-moving companies were another two options for householders to transfer their used appliances. The ratio was quite low and accounted for 1~3% for each.

3.3.2 Total transportation load

Fig 6 indicates the calculation results of the collection and transportation frameworks for the used EHA in Beijing via and without using the transfer stations. The TTL will keep increasing for both scenarios due to the increase of the amount to be collected. The TTL and ATD in case of not using the transfer stations is nearly 15% higher than that by using the transfer stations.

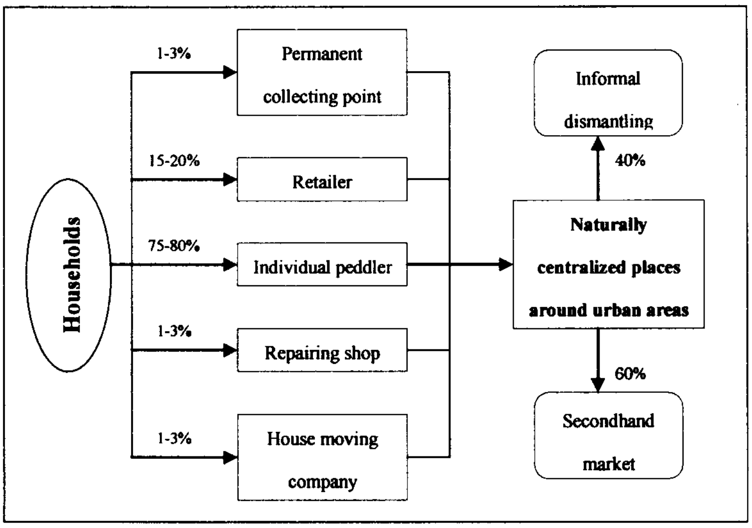

Fig 5: Current status of the collection of used EHA in Beijing.

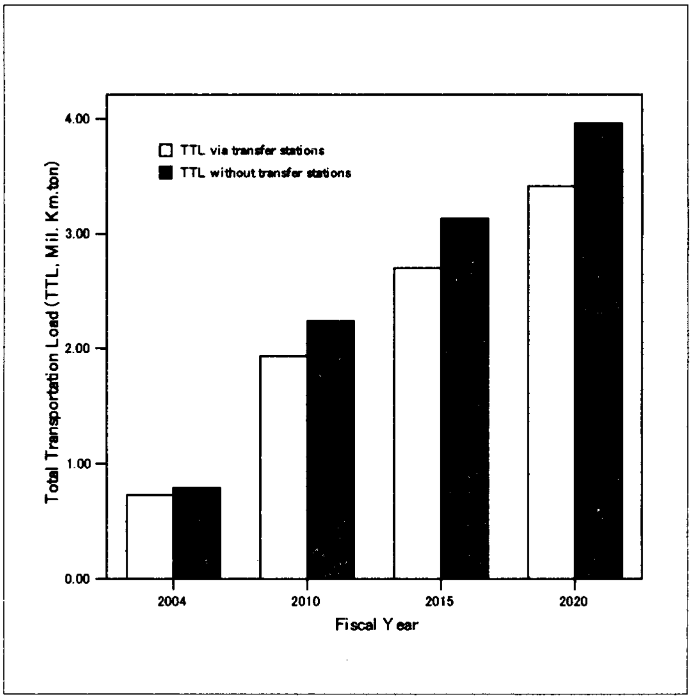

Fig 6: Optimization result of total transportation load.

3.3.3 Average oil consumption of the transportation

The AOC and pollutant emissions from the vehicles of transportation in the case of using the transfer stations are calculated to evaluate the environmental impacts. The vehicle to transport the appliances from the streets to the transfer stations is assumed to be the truck with the capacity of 1.5 metric tons. The vehicle used to transport appliances from the transfer stations to the secondhand market and recycling facilities is assumed to be the truck with the capacity of 4 metric tons. The index of oil consumption and emission factors comes from the Vehicle Emission Research Institute, Tsinghua University *(VERI 2005)*. The truck presently follows current national emission standards and shall meet higher standards for the next phase starting from 2010. Calculation result of AOC in scenario of using the transfer stations is listed in Fig 7. The AOC for the transportation of the recycling part is 2.64 l/t in 2004 and will increase to about 3.20 l/t by 2010 due to the great increase of ATD. The AOC for the transportation of the reusing part is about 5.40 l/t.

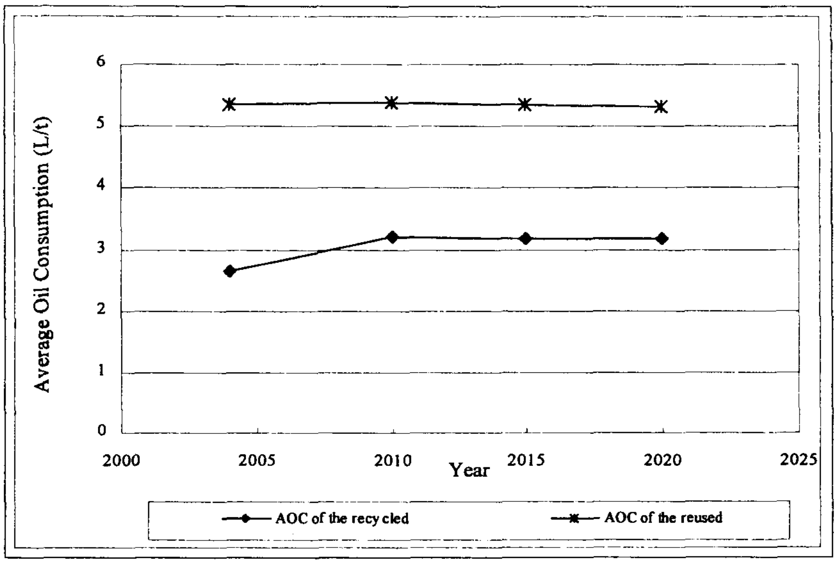

Fig 7: Average oil consumption for the transportation of used appliances.

3.3.4 Current cost estimation for the collection and transportation

The total cost for collection and transportation is made up of the cost for collection from households, the cost for intermediate treatment and the cost for transportation. The costs for collection and intermediate treatment are determined by the input of manpower and the space for storage and transfer that are fixed in average within a specific region. The total cost can be assumed to be proportional to the TTL. The optimized result for TTL is regarded also as the best scenario for the total cost. Fig 8 indicates the estimation result. Current cost for collection and transportation of the waste appliances for recycling ranges 20 to 30 RMB (unit of Chinese currency, 1USD ≈ 8.0 RMB) per unit. The cost for the appliances to be reused is 25~35 RMB per unit, which is a little bit higher due to longer distance of transportation. Refrigerators cost the most because they have the largest average weight when observing from the types of the appliances.

3.4 Economic evaluation of optional recycling processes for waste EHA

As a part of assessment on waste EHA management frameworks, the recycling technological options were classified for the collected waste EHA. The revenues or costs were evaluated for each of the classified recycling processes.

Several typical waste EHA recycling plants in Japan were visited during August and November of 2006. The classified typical recycling processes from literature review were confirmed. Three levels of processes were defined. Level 1 is only to manually separate the components or materials that can be disassembled. Level 2 is to shred the rest parts after manual dismantling and separate the metals by magnetic and eddy current separators for material recovery. Level 3 is the most advanced and has the highest ratio of material recovery. It separates the plastic mixtures with other residues by wind separating unit after the same processes as level 2. The hazardous materials are disposed of by environmental sound methods in each level of process described above. The residues are assumed to be sent to the landfill site for final disposal.

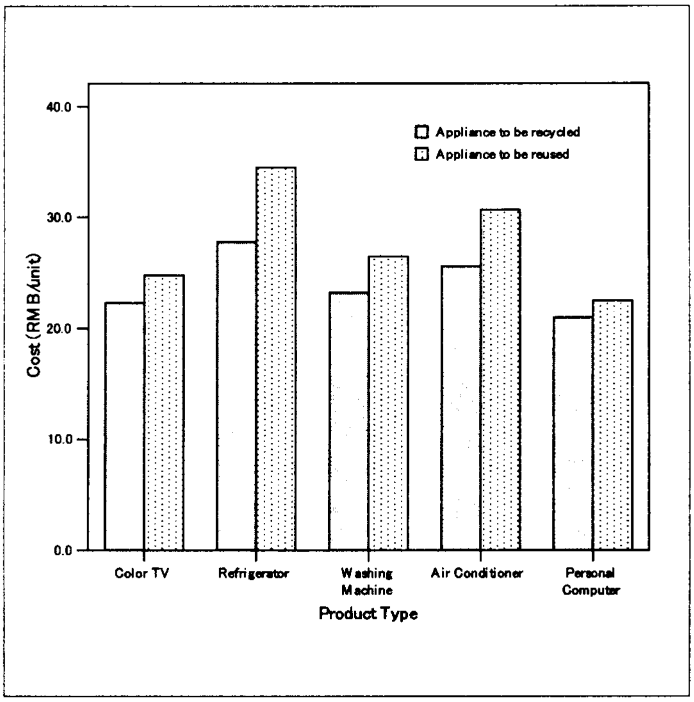

Fig 8: Current cost for the collection and transportation of used appliances.

The revenues or costs of the three levels of technological options are indicated in Fig 9. The revenues from the recycling of the five main types of appliances all increase along with the recycling processes become more advanced from level 1 to level 3. The revenues range 90 ~ 240 RMB/unit for the scenario of level 3. The revenues are 45 ~ 220 RMB/unit for the process of level 2. The revenues decrease greatly for the process of level 1. It costs about 100 RMB/unit for waste refrigerator and 6 RMB/unit for waste washing machine. It is because that waste refrigerator has higher ratio of materials unsuitable to be manually dismantled. Waste air conditioner has the largest revenue from the recycling process due to high percentage of copper components and high market price of copper.

The make-up of revenue from the recycling process of level 2 is indicated in Fig 10. Initial investment for the buildings and mechanical equipments accounts for 30 ~ 45% of the expenditure. Cost for labor input is only about 10% of the total expenditure due to the low labor price currently in China. Expenditures for the treatment of hazardous materials are quit different if observing from the type of the appliances. The revenues from the materials separated by mechanical units make up of the main stream of the revenues. This explains the necessity to introduce advanced process with mechanical equipments for the recycling of the waste electronic home appliances to obtain higher revenue and ratio of material recovery.

3.5 Profitability analysis of the entire management frameworks

The economic availability of the entire management frameworks of waste EHA was evaluated by integrating the prices paid to the householders, the cost for the collection and transportation and the revenue of the recycling processes. Since the process of level 1 is not the option for recommendation from economic viewpoint, the revenues of the entire management frameworks are indicated in Fig 11 for the cases of using recycling processes of level 2 and 3. The revenues of waste TV, refrigerator and washing machine are negative. Only the revenues of waste personal computer of both scenarios are positive. The recycling facilities should be financed if the prices paid to the householders are kept unchanged.

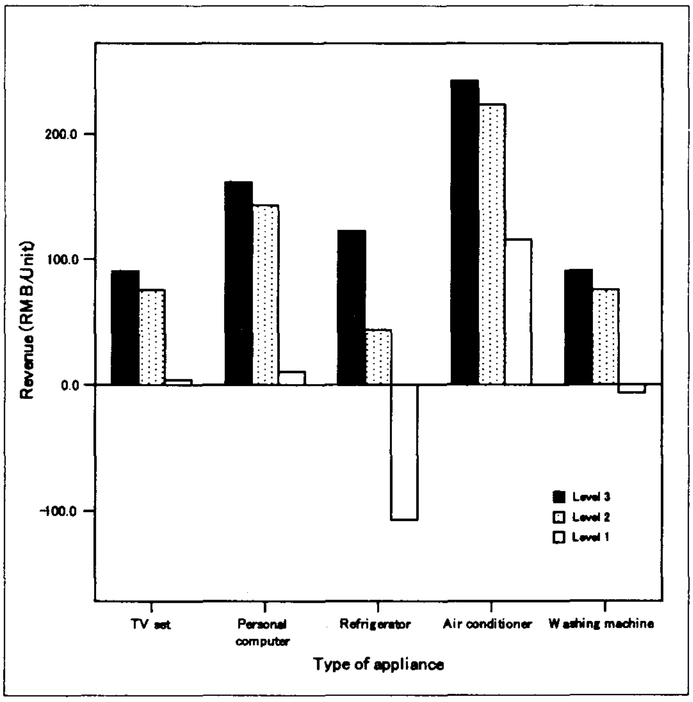

Fig 9: Revenue of the recycling processes of waste EHA.

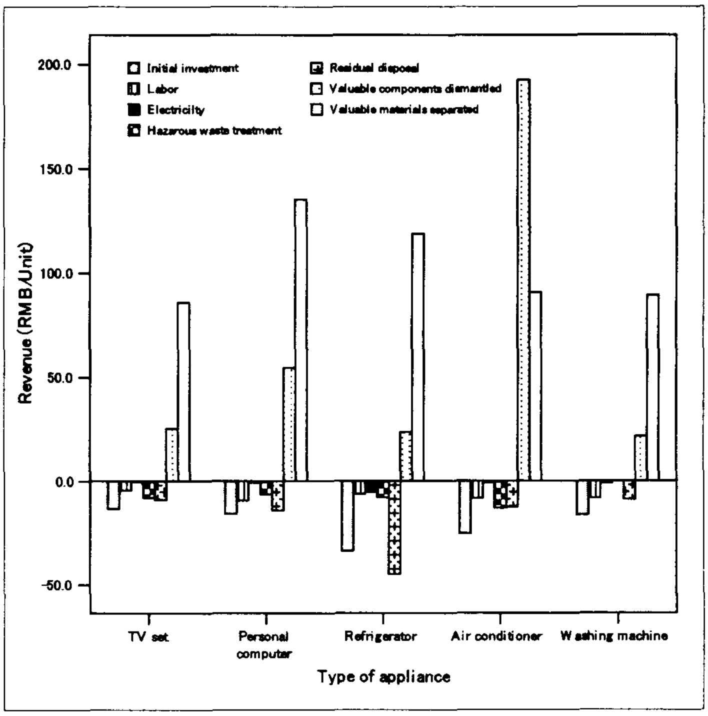

Fig 10: Revenue fractions of the recycling process of level 2.

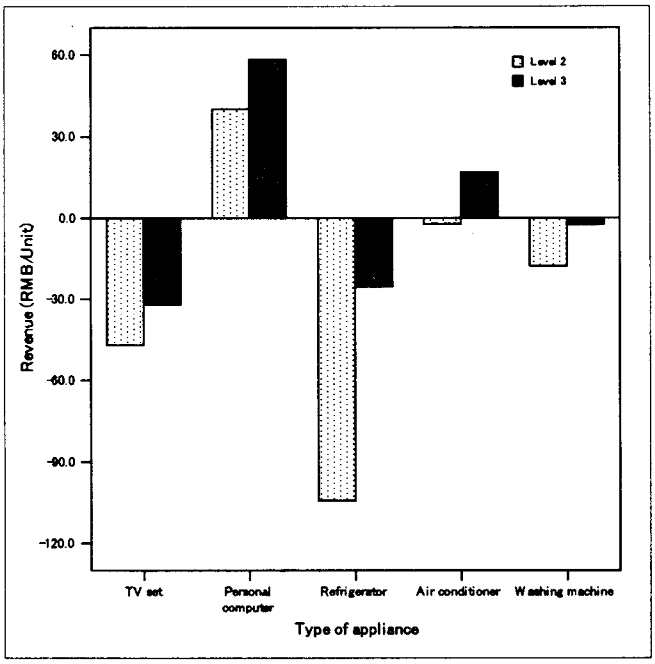

Fig 11: Revenue of the whole management framework.

The profitability of the management framework in case of using the recycling process of level 2 is examined as Fig 12. The income consists of the sales of materials recovered from the appliances as resources. Variable costs include the money paid to the owners, cost of collection and transportation, the processing expenses of the recycling facility and the disposal costs for the materials left after processing. Fixed costs are made up of the depreciation expenses of initial investment, ground rent and other business expenses such as system maintenance, etc. The marginal profit (income minus variable costs) can be calculated based on evaluated income and variable costs. The marginal profit depends greatly on the prices paid to the appliances owners. Calculations are made at four price levels between 0 and 40% of the current price paid to the householders when collecting their used appliances (the horizontal lines in the chart). Operating rate is very influential because recycling has strong characteristics of a facilities industry. The fixed cost is given according to various operating rates (in other words, the extent to which home appliances enter the system compared to its estimated capacity). As the result, it appears that the break-even level can be attained if the price paid to the owners can be reduced to less than 40% of its current level. The less to be paid, break-even point could be attained at lower operating rate. An operating rate of roughly 60% should be achieved in case of paying 30% of current prices to the householders.

4. Conclusions and suggestions

The profitability of the entire management framework could be realized if the price paid to the householders could become lower. This is possible from the questionnaire survey on the intentions of householders to the recycling cost. As the conclusion, it is suggested that the key for the establishment of a formal management framework for electronic waste in Beijing is to change the traditional expectation of householders to the values of the used appliances and encourage their transfer to the formal collection system at lower prices (e.g. less than

40% of current prices). The collection activities of the existing private collectors must be regulated and integrated into the establishing formal collecting system to ensure the operating rate of the recycling facilities.

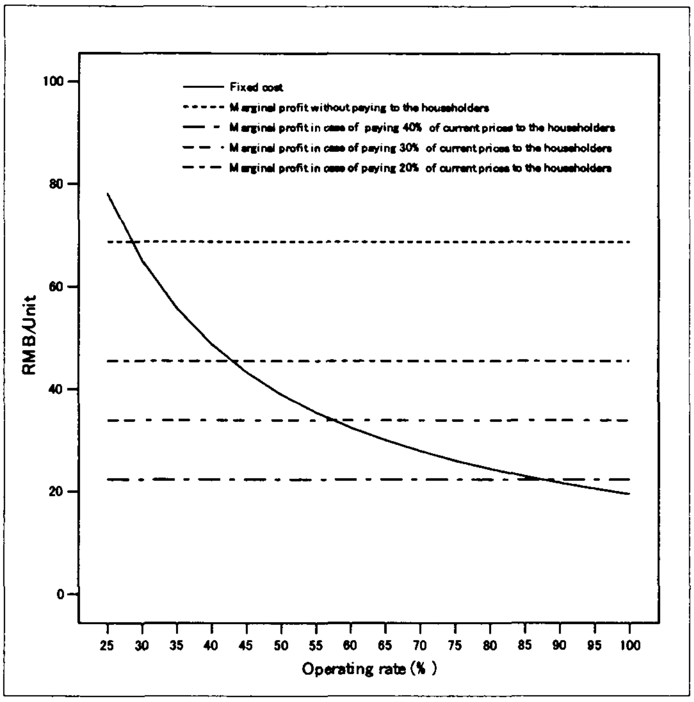

Fig 12: Fixed cost and marginal profit per unit of home appliance recycling.

REFERENCES

Cui, J. Forssberg, E. (2003): Mechanical recycling of waste electric and electronic equipment: a review. *Journal of Hazardous Materials.*, 9 (2003), P243~263.

Jofre, S., Morioka, T. (2005): Waste management of electric and electronic equipment: comparative analysis of end-of-life strategies, *Journal of Material Cycles and Waste Management*, 7, P24~32.

Li, J.H., Honda, S. and Liu, T.Z. (2004): Survey and analysis on the management of electronic and electric wastes in typical countries of Asia. In: Proceeding of the 3rd workshop on material cycles and waste management in Asia, Tokyo, 14-15 December, P39~48.

Liu, X., Tanaka, M. & Matsui, Y. (2006): Electrical and electronic waste management in China: progress and barrier to overcome. Waste Management & Research, 24, P92~101.

Lohse, J., Winteler, S. & Wulf-Schnabel, J. (1998): *Collection Targets for Waste from Electrical and Electronic Equipment (WEEE)*. Okopol Institute fur Okologie und Politik Gmbh.

Matthew, H. , McMichael, F. , Hendrickson, C. & Hart, D. (1997): *Disposition and End of Life Options for Personal Computers,* Design initiative technical report #97-10, Carnegie Mellon University.

Vehicle Emission Research Institute, Tsinghua University (VERI) (2006): Index of oil consumption and emission factors and levels of trucks to meet standards at different phases.