Waste Management 33 (2013) 714–721

Contents lists available at SciVerse ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

A material flow analysis on current electrical and electronic waste disposal from Hong Kong households

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ARTICLE INFO

Article history:
Received 5 April 2012
Accepted 5 September 2012
Available online 6 October 2012

Keywords:
Electronic waste
Material flow analysis
Waste management
Hong Kong

ABSTRACT

A material flow study on five types of household electrical and electronic equipment, namely television, washing machine, air conditioner, refrigerator and personal computer (TWARC) was conducted to assist the Government of Hong Kong to establish an e-waste take-back system. This study is the first systematic attempt on identifying key TWARC waste disposal outlets and trade practices of key parties involved in Hong Kong. Results from two questionnaire surveys, on local households and private e-waste traders, were used to establish the material flow of household TWARC waste. The study revealed that the majority of obsolete TWARC were sold by households to private e-waste collectors and that the current e-waste collection network is efficient and popular with local households. However, about 65,000 tonnes/yr or 80% of household generated TWARC waste are being exported overseas by private e-waste traders, with some believed to be imported into developing countries where crude recycling methods are practiced. Should Hong Kong establish a formal recycling network with tight regulatory control on imports and exports, the potential risks of current e-waste recycling practices on e-waste recycling workers, local residents and the environment can be greatly reduced.

1. Introduction

Electrical and electronic waste, or e-waste, is a generic term for electrical and electronic equipment (EEE) that has come to the end of its useful life. Another commonly used acronym is WEEE, waste electrical and electronic equipment. In the past few decades, treatment of e-waste has become a global waste management challenge owing to the fast obsolescence of modern technologies and the potential environmental and human exposures to hazardous materials during their recycling and disposal (de Oliveira et al., 2012). In addition, the transboundary movement of e-waste from developed countries to developing ones, where they are dumped or improperly managed, causes severe environmental and health problems for decades or centuries to come (Shinkuma and Huong, 2009).

Information on the generation, disposal and flow of e-waste is important for the planning of cost-effective treatment and handling capacity in addition to, estimating the scale and possible consequences of the mishandling of e-waste. Yet accurate information on the material flow of e-waste in an economy is hard to obtain, as it is often the case that secondary and waste products do not appear in national statistics of production, sales and traded-in goods (Nnorom and Osibanjo, 2008). Hong Kong is often mentioned as a transit port through which e-waste travels from developed nations to China for recycling in the informal sector (Information Services Department [ISD], 2009; Puckett et al., 2002; Wong et al., 2007). However, there is a dearth of studies that explores the actual e-waste situation in Hong Kong. Significant amounts of e-waste are generated locally and, in spite of the legislative efforts of the Hong Kong Special Administrative Region (SAR) Government, equally significant amounts are imported and stored temporarily in the rural areas awaiting re-export. In order to provide support to the Hong Kong SAR Government for the forthcoming producer responsibility scheme (PRS) on e-waste controls (see Section 1.1), a material flow study was conducted to trace the flow of e-waste after its disposal by Hong Kong households. This study is the first of its kind in Hong Kong SAR and it is acknowledged that there are still gaps in the information that need to be filled. Nevertheless, the findings are indicative of the current situation and are consistent with similar studies in Mainland China where a similar e-waste recovery process is in place (Liu et al., 2006; Streicher-Porte and Yang, 2007; Yang et al., 2008).

1.1. PRS control on e-waste in Hong Kong

With a growth rate of 2% per year, e-waste is one of the fastest growing components of the municipal solid waste stream in Hong Kong (Environment Bureau, 2010). Chung et al. (2011) estimated that Hong Kong households alone generate approximately 80 thousand tonnes of televisions, washing machines, air-conditioners,

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http://dx.doi.org/10.1016/j.wasman.2012.09.007

refrigerators, and computers (TWARC) as waste annually. These e-waste figures are likely to continue to increase owing to the proliferation of electronic and electrical devices, falling retail prices and planned obsolescence (de Oliveira et al., 2012) although the final results also depend on the popularity of downgauging designs and multi-functional EEEs.

To tackle the e-waste problem, the Hong Kong Government has proposed a new PRS for the proper disposal of e-waste with priority being given to the treatment of TWARC waste (Environment Bureau, 2010). PRS is an environmental management tool founded on the Extended Producer Responsibility (EPR) notion. EPR is becoming increasingly popular as a theoretical basis for hammering out the management solution for the management of e-waste and has been adopted by many developed countries in the past decade (Ongondo et al., 2011; de Oliveira et al., 2012). The Directive on Waste Electrical and Electronic Equipment in the European Union, the Home Appliance Recycling Law and the Law for the Promotion of Effective Utilisation of Resources in Japan, and the Waste Disposal Act in Taiwan are but a few examples. The Organisation for Economic Co-operation and Development (OECD) (2001) defines EPR as “an environmental policy approach in which a producer’s responsibility for a product is extended to the post-consumer stage of a product life cycle”. By adopting EPR, both the physical and financial responsibilities for end-of-life treatment may be shifted fully or partially to the producers and away from governments and albeit to a lesser extent, may also motivate producers to incorporate environmental initiatives into the design of their products.

Based on overseas experience, the Hong Kong Government estimates that an appropriate level of recycling fees to be charged to consumers would be HK$100–250 for a piece of home appliance and a lower amount for computer products. This fee would be collected at the point of sale and would be used to fund a recycling plant with an annual handling capacity of 30,000 tonnes (Cheung, 2011), although this represents less than 40% of the locally generated TWARC waste from households when compared with the estimation of Chung et al. (2011). In addition to such treatment facilities, effective logistical arrangements for collection of the material will be central to implementing a PRS in Hong Kong, where the majority of residents live in high rise buildings and have limited, if any, storage space in their flats. Collection points must be widely available and highly accessible to consumers as they will need to dispose of e-waste immediately once an item breaks or becomes obsolete, and will require prompt collection and treatment. However, specific details of the scheme are still to be disclosed as no timetable has been agreed for implementation (Cheung, 2011).

According to the Environment Bureau (2010), 80% of e-waste generated in Hong Kong is recycled and the majority of it is sold through second hand dealers to developing countries for recycling. The high volume of e-waste that flows through the existing collection and recycling system demonstrates that this system is highly effective and popular amongst consumers. Although it is known that second hand dealers do play a role in this process, the flow of materials disposed of by consumers through their intricate network remains largely unknown even to the Hong Kong Government.

1.2. Material flow analysis (MFA)

Based on the law of material conservation, a MFA systematically connects the sources, pathways and the intermediate and final sinks of a material (Brunner and Rechberger, 2004; Steubing et al., 2010). The results of a MFA can be controlled by simply comparing all inputs, stocks and outputs of a process, making it an attractive decision-support method tool in resource management (Brunner and Rechberger, 2004). Several studies have used MFA to quantify and trace the flow of particular e-waste categories, including computers and consumer durables (Kang and Schoenung, 2006; Kumar and Shrihari, 2007; Oguchi et al., 2008; Steubing et al., 2010), and to identify networks and chains connecting different phases of the EEE life cycle and the associated stakeholders (Streicher-Porte et al., 2005; Jain and Sareen, 2006).

The first step in conducting a MFA for e-waste in a particular country/region/city is to establish its e-waste inventory. Five methods have been developed to determine the e-waste inventory (UNEP, 2007). The data requirements for each of the methods are summarised in Table 1. Sales data is usually derived from production, import and export statistics while stock data, or the amount of EEE currently in service, can be ascertained from the penetration rates (i.e. percentages of households/workplaces currently containing a particular EEE) or derived from assumptions. The average lifetimes of items on the other hand, are more variable and depend greatly on the behaviour and habits of individual consumers.

1.2.1. Time step method

E-waste calculations made using the time step method are based on the difference between private and industrial stocks between two consecutive years plus the sales in that period (Streicher-Porte, 2006). This method should ideally be applied to saturated markets where each obsolete item is immediately replaced by a similar new one. The method can be mathematically represented for the year t as:

$$\text{E-waste generation } (t) = [\text{stock } (t-1) - \text{stock } (t)] + \text{sales } (t) \quad (1)$$

1.2.2. Market supply method

The market supply method uses data on production and sales. E-waste generation is estimated on the basis of historical production and sale figures by extrapolating backwards over the assumed lifespan of an item. Mathematically, it can be represented as:

$$\text{E-waste generation } (t) = \text{sales } (t-d_n) + \text{reuse } (t-d_s) \quad (2)$$

where d_n is the average lifetime of new items and d_s is the average lifetime of second-hand items.

The market supply method has been widely used to estimate e-waste generation (Streicher-Porte et al., 2005; Jain and Sareen, 2006; Kumar and Shrihari, 2007) because usually, sales data are readily available from market research, trade institutes or official statistics and are of good quality.

1.2.3. Carnegie Mellon method

First developed by Matthews et al. (1997), the Carnegie Mellon Method is a data intensive calculation of e-waste quantities based on historical sales data, typical lifetimes, recycling and storage information. It is a variation of the market supply method but additionally considers the post consumption behaviour of consumers for which there are four options: (1) reuse; (2) storage; (3) recycling and (4) landfill (UNEP, 2007). However, country specific data, such as recycling rates and consumer behaviour and preferences, such as lifespan, in addition to a large volume of historical sales data are needed for the model to be applied. The model incorporates a sophisticated study of a product’s end-of-life cycle and is

Table 1
Data requirements for determining e-waste inventory.

Calculation method	Data requirements		
	Sales	Stock	Average lifetime
Time step	✓	✓	
Market supply	✓		✓
Carnegie Mellon	✓		✓
Approximation 1		✓	✓
Approximation 2	✓		

therefore recommended for extensive examination of individual products because the calculation of e-waste generation is more clearly structured (European Environment Agency [EEA], 2002; UNEP, 2007).

1.2.4. Approximation 1

The Approximation 1 method, sometimes known as the Consumption and Use method, uses a simple formula to estimate e-waste quantities on the basis of stock and average lifetime data. It is particularly useful when reliable stock data for an EEE item are available (EEA, 2002). The method can be represented mathematically as:

$$\text{E-waste generation } (t) = \frac{[\text{Stock}_{\text{private}}\ (t) + \text{Stock}_{\text{industry}}\ (t)]}{\text{Average lifetime}} \tag{3}$$

where:

$$\text{Stock}_{\text{private}} = \frac{\text{Number of households} \times \text{Household penetration rate}}{100} = \frac{\text{Population}}{\text{Average household size}} \times \frac{\text{Household penetration rate}}{100}$$

$$\text{Stock}_{\text{industry}} = \frac{\text{Number of workplaces} \times \text{Workplace penetration rate}}{100} = \frac{\text{Number of employees}}{\text{Number of users per EEE}} \times \frac{\text{Workplace penetration rate}}{100}$$

1.2.5. Approximation 2

According to UNEP (2007) the Approximation 2 formula uses sales statistics and assumes that with the sale of a new appliance, an obsolete appliance will be disposed of. The advantage of this method is that no historical data is required and the method can be represented for a particular year, *t*, by Eq. (4):

$$\text{E-waste generation } (t) = \text{sales } (t) \tag{4}$$

However the underlying assumption that the purchase of a new product leads to the same quantity of waste from the old product implies that this method can only be applied to fully saturated markets.

Once the e-waste inventory is established, identification of the e-waste stream, the relevant processes and the relationship between the stakeholders is carried out. The location, activities at each step, and estimation of the quantity of material handled in each of the processes are documented. Semi-structured interviews may be useful to obtain an understanding of the identification and practices of relevant stakeholders in the informal sector (UNEP, 2007).

2. Material and methods

Despite being ranked as one of the world's most developed cities, Hong Kong lags behind in the provision of reliable TWARC trade and sales statistics (Chung et al., 2011). Therefore, two surveys were devised by the authors to obtain information on TWARC waste generation and recycling. One survey interviewed households directly to obtain information on their disposal preferences (hereafter Consumer Disposal Pattern Survey). The second was aimed at e-waste traders involved with the collection of TWARC waste from Hong Kong households (hereafter Private E-waste Trader Survey).

2.1. Consumer Disposal Pattern Survey

To investigate consumer behaviour, a survey questionnaire was distributed to households to obtain information on their (household only) TWARC waste disposal patterns. The methodology and amounts generated were reported in Chung et al. (2011). In summary, a total sample size of 1230 households was covered.

2.2. Private E-waste Trader Survey

To trace the flow of TWARC waste after disposal from a household, a second questionnaire was designed to interview private e-waste traders on their trading practices. To the best of our knowledge, no systematic study has so far been conducted on the trade practices of the private e-waste recycling sector in Hong Kong. Therefore, the aims of the Private E-waste Trader Survey were to establish: (1) the flow of TWARC waste after collection by e-waste traders; and (2) the trade practices of the private recycling sector. Most e-waste traders are not registered and may not even have a permanent location for their operations. Therefore, the research team decided to visit the districts that were known to have relatively abundant e-waste traders. Of the urban areas of HKSAR, Hong Kong Island and Kowloon are the two regions that are most popular with e-waste traders owing to the high population density. All e-waste traders encountered on the street were invited for an interview if they were engaged in collecting any TWARC items. Snowball sampling was used if any of the respondents were willing to introduce other e-waste traders to the research team. Reluctant respondents were re-visited two to three times in an effort to keep the refusal rate as low as possible. Altogether, 30 successful interviews were achieved out of 56 e-waste traders approached, yielding a response rate of 53.6%. The general reluctance of e-waste traders to be interviewed might be explained by the fact that many of their operations did not fully conform to laws which was also the phenomenon noted for their counterparts in Delhi (Streicher-Porte et al., 2005). For instance, some of them did not bother to recover refrigerants from old fridges and air-conditioners when they dismantle them. It was also believed that some e-waste traders employed illegal labour (Wong, 2005). In addition, the public has become concerned about the potential environmental and human health risks that could arise during recycling of e-waste containing hazardous materials (Lam, 2011; ISD, 2011) and recent legislative consultations on regulatory measures has shone a spotlight on the industry.

Owing to the hard-to-identify nature of this group of respondents, only non-probability sampling method was used and the assumption had to be made that the practices of the e-waste traders interviewed were representative of all those in HKSAR. Cantonese, the main dialect in Hong Kong, was generally used to conduct the interviews while interviews with e-waste traders of ethnic origins other than Chinese were conducted in English. Although they are not private in nature, ten charity organisations that collect e-waste donations were also interviewed using the same questionnaire on top of the 30 e-waste trader respondents.

Since the findings of the Consumer Disposal Pattern Survey have been reported elsewhere, only the data treatment and findings of the Private E-waste Trader Survey will be discussed in this paper. The material flow of household TWARC waste was then constructed following a modified consumption and use approach, by integrating the results of the Consumer Disposal Pattern and the E-waste Trader Surveys.

3. Results and discussion

3.1. Types and roles of e-waste traders

Hong Kong's current private e-waste recycling network can be broadly classified into two tiers. Tier 1 recyclers are those who collect e-waste directly from households. Tier 2 recyclers collect most of the TWARC waste from tier 1 recyclers for further handling or processing. Table 2 summarizes the characteristics of the different outlets for TWARC waste from Hong Kong households.

The current private e-waste recycling network is complex and existing knowledge (other than that collected in the present study) is piece-meal in nature. Revealed in our survey, e-waste collectors were the main parties in this informal e-waste trading network. They were very visible in densely populated urban residential areas and provided door-to-door collection services to households. They would commonly pay the scrap value of the e-waste to the last user. None of the e-waste collectors approached in the survey had a permanent business address. Instead, they got their business by displaying signboards on the streets that contain their contact information. Collected e-waste items were resold to tier 2 recyclers usually on the same day or, occasionally, stored in their homes, vehicles or in public areas. By contrast, scrap metal collectors handled TWARC wastes that were directly delivered to their stores. They rarely offered a door-to-door collection service and then only if there were significant quantities of e-waste available for collection. In addition to collecting e-waste, scrap metal collectors also dealt in other recyclables such as scrap metal and paper. Based on the results of the survey, e-waste accounted for about 8% (by weight) of the scrap metal collectors' business. Similar to the e-waste collectors, smaller scrap metal collectors would resell collected e-waste to tier 2 recyclers as soon as possible owing to their limited storage space. They would also extract any valuable metals by dismantling TWARC waste, a process which is rarely done by e-waste collectors.

Television, air conditioner and refrigerator repair shops were also approached in the survey and they represent another type of tier 1 e-waste traders. While television repair shops indicated that they would only collect televisions sent to their stores, air conditioner and refrigerator repair shops would provide door-to-door collection services to the customers. However, refrigerator repair shops would only collect items that still had a marketable value in the second-hand market whereas air conditioner repair shops would collect items that were beyond on-site repair. All shops, however, gave priority to the refurbishment of collected items for resale on the second-hand market. Dismantling may also be conducted to extract spare parts for reuse in future jobs or sold to other private traders for recycling. Dismantled parts without scrap value would be discarded directly as municipal solid waste and landfilled in Hong Kong.

Most tier 2 recyclers were involved in exporting TWARC waste sourced from tier 1 recyclers. TWARC may or may not be dismantled prior to export. E-waste exporters normally specialise in trading one type of intact TWARC. Collections from tier 1 recyclers were made by lorry on a fixed route once or twice a day. Although these driving routes may vary, e-waste exporters were found to be clustered in Shum Shui Po, a low-income and densely populated residential district in Hong Kong. The respondents indicated that Africa and South Asia were progressively replacing Mainland China as the main markets receiving e-waste exported from Hong Kong.

Charity organisations on the other hand sourced e-waste through donations from households, private business corporations or institutions. However, since charity organisations are non-profit-making and have limited resources available to support such programmes, door-to-door collection services were provided to households only when the volume of the donations met a minimum requirement. Donations were not limited to e-waste but the requirement for a collection is normally at least three large bags of goods. In general, households were encouraged to bring their donations directly to the charity organisations. Donated items would either be given away to low income households or sold at low prices to people in need. One organisation also exported donated goods to the underprivileged in developing countries.

Through two charity organisations, the Hong Kong Environmental Protection Department (HKEPD) operates a WEEE Recycling Programme with the aim of diverting donated e-waste from the general waste stream for reuse and recycling. St. James Settlement, with a recycling workshop at the newly established EcoPark, collects household appliances such as televisions, refrigerators and washing machines, while Caritas (HK), operates a computer refurbishing and recycling workshop in the city centre. Donors can drop off obsolete items directly, either at the recycling workshops, at collection points managed by the two organisations, or to the mobile collection vehicle operated by the HKEPD. Door-to-door collection services are also provided for specific types of EEE (e.g. televisions and refrigerators), but owing to limited resources, the waiting times are normally long. Occasionally some housing estates will organise e-waste drives where proceeds would be donated to the appropriate organisations for further processing. Upon collection at the recycling workshop, both of the charity organisations would inspect the collected items, have them repaired if appropriate and donate repaired ones to the needy. Those for which there is no suitable recipient would be sold through charity sales while broken items are dismantled for recycling (HKEPD, 2011).

3.2. Disposal of TWARC waste from Hong Kong households

Based on the Consumer Disposal Pattern Survey, where each respondent was interviewed on their adopted method of disposal for the previous set of TWARC equipment they owned, and under the assumption that each household disposes of similar numbers

Table 2
Description of key outlets of TWARC waste from Hong Kong households.

Disposal outlets	Tier	Descriptions
Building cleaners	1	Cleaners responsible for daily waste disposal within building of residence
Delivery workers	1	Workers (hired/contracted) by retail companies responsible for delivering newly purchased TWARC to households while removing the obsolete items at the same time
Non-profit making organisations	1	Government or charitable organisations may run recycling/recovery programmes for e-waste which are then reallocated to households in need, sold at a low price to low income families, or be formally dismantled for recycling
Retail stores	1	Where end-users may purchase TWARC of the same type at lower prices when they return obsolete items to the store directly
Communal refuse collection areas	1	Direct disposal by end-users at daily waste collection areas at or near place of residence. Unwanted TWARC normally occurs in two forms, either intact or disassembled where users retain useful parts
E-waste collectors	1	Small scale operators whose business is limited to e-waste trading only. Usually erect signboards on the street providing contact information, types of e-waste collected and indicative redemption values
Repair shops	1	Specialises in door-to-door repairing of broken items. Workers will collect broken items for refurbishment/dismantling at their stores if items are beyond repair
Scrap metal collectors and/or exporters	1 and 2	Collects a variety of recyclables in addition to e-waste and have permanent depots in which they operate their business. Large scrap metal collectors often are exporters themselves
E-waste exporters	2	Source TWARC and other e-waste from other traders for exportation with or without dismantling. Usually specialises in trading one type of e-waste

of TWARC wastes over time, the percentage distribution of adopted disposal methods (by item) by households are indicated in Fig. 1 (Chung et al., 2011). As expected, the majority of household TWARC waste is handled by e-waste collectors, not only because they provide door-to-door collection services, but also because they pay the scrap value of the EEE to the last user. Moreover, for washing machines, air conditioners and refrigerators, the most popular method of disposal is to request delivery workers to remove the obsolete EEE from the household when they deliver a new machine This is not the case for computers, which may reflect the ease of disposal for the users in relation to the size of the items. On the contrary, "self disassembly and keep the useful parts" is the most common process for disposal of desktop and laptop computers in comparison to the other studied EEE. A higher proportion of surplus desktop and laptop computers are also "donated to non-profit making organisations". For the bulkier household TWARC wastes, however, the pattern of disposal is more or less similar. It should be noted that the "others" category includes giving obsolete TWARC wastes to friends or relatives, or leaving it for the next occupant of the flat from which the respondents are moving out. These findings are in line with a study done by Liu et al. (2006) on TWARC waste disposal from Beijing households. In their study, the largest proportion of waste (56.8%) was sold to pedlars, the equivalent of e-waste collectors in Hong Kong, while 16.9% were directly discarded, which was higher than the proportion found for Hong Kong households (5.5%) in the present study.

3.3. MFA calculations, assumptions and limitations

The obsolescence rate of TWARC waste was estimated to be 80,433.1 tonnes/yr (excluding plasma and LCD televisions) and items that had accumulated in storage amounted to 26,514.1 tonnes (Chung et al., 2011). In constructing the quantity of TWARC waste going into each disposal process from households, i.e., all tier 1 recyclers, the percentages for the disposal method adopted for each type of TWARC waste (as shown in Fig. 1) were multiplied by their respective average weights as reported in Chung et al. (2011).

The results from the E-waste Trader Survey were then incorporated into the material flow model to represent the trade flows from tier 1 recyclers to tier 2 recyclers. Each respondent was asked to estimate the amount of TWARC waste handled per week such that an average annual throughput could be calculated for the MFA. However, because this calculation was based on information provided by the respondent and because the number of TWARC handled per week varied, the calculated throughput can only represent the aggregate of the TWARC products handled by the e-waste traders.

Several assumptions were made in incorporating the results from the Private E-waste Traders Survey into the MFA calculations. The first is that the respondents are representative of their counterparts. While the small sample size may have limited the possibility of generalising the responses to the whole population, the reported practices of the major e-waste traders (the last four categories mentioned in Table 2) were found to be homogeneous. Second, each group of e-waste recyclers trades similar types and volumes of TWARC waste. Third, as retailers do not operate their own e-waste treatment facilities, it was assumed that traded-in items are disposed of or exported. Fourth, non-profit making organisations also collect TWARC from institutions and private business corporations, but as separate estimates of the proportion of household TWARC waste going to each disposal outlet is not available, they were assumed to be equal. In addition, while the surveys confirmed that building cleaners and delivery workers sold collected TWARC to recyclers in tiers 1 and 2, accurate percentage estimates of the quantity of material going into each possible outlet could not be determined. This last point, while not an assumption, is one of the limitations of this study. In summary, the tonnages collected by building cleaners, delivery workers, retailers and non-profit making organisations were averaged out among all the identified recycling pathways. Finally, it was believed by the authors that the retention of useful parts from user disassembled TWARC waste represents only a small portion of the appliance. In view of the lack of data on the percentage kept, no separate breakdown on extracted TWARC parts was made and hence, the tonnage from "Self disassembly and keep the useful parts" option, calculated using average weights of intact TWARC, was incorporated as a whole into the "Disposal as general waste" calculation.

3.4. Material flow of TWARC waste from Hong Kong households

As previously mentioned, the majority of TWARC waste disposal from households was handled by e-waste collectors (see Fig. 2), with a throughput of 41,900 tonnes/yr. Most of the household

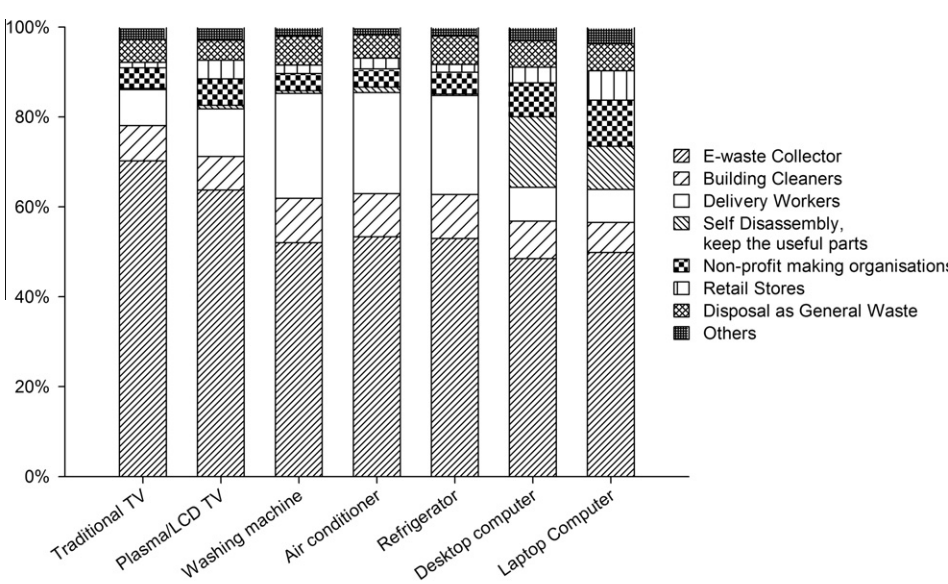


Fig. 1. Disposal methods for household TWARC waste. *Source*: Chung et al. (2011).

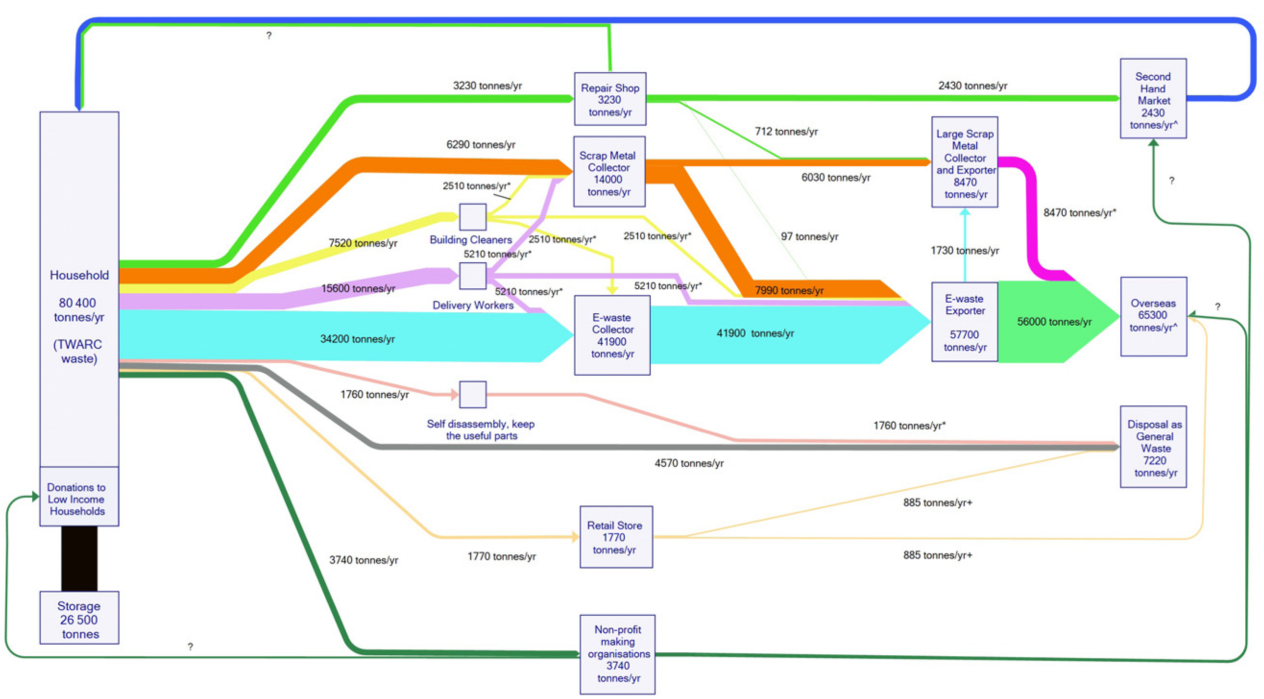
TWARC waste was sold to the e-waste collectors while some may have been removed without any redemption value. In addition to direct collection from households, 23.4% of households requested building cleaners or delivery workers to dispose of TWARC. However, this cannot be regarded as a method of disposal since both building cleaners and delivery workers were known to sell collected TWARC waste to e-waste collectors. TWARC handled by repair and scrap metal collector stores were either delivered directly to them or collected from the respective households. Approximately 75% of TWARC collected from repair shops would be resold in the second-hand market while the remaining 25%, and most of the TWARC collected by scrap metal dealers, were eventually be exported. Donations to non-profit making organisations and trading-in at retail stores were other methods of TWARC waste disposal from households. This study also found that each year, 7220 tonnes of household TWARC waste or 1.0 kg/capita reach the public waste disposal facilities (Fig. 2). This value was lower than the 2.1 kg/capita in the Netherlands in 2011 for household e-wastes, mostly small electrical appliances, that were incinerated (Huisman et al., 2012).

3.5. Consequences of the export of e-waste

From current calculations, 57,700 tonnes/yr of TWARC waste were exported by e-waste exporters while 8470 tonnes/yr of TWARC waste were thought to be exported to overseas by large scrap metal collectors cum exporters. This amounts to a total export of 65,300 tonnes/yr or about 80% of the TWARC waste generated by households each year, bearing in mind that plasma and LCD televisions as well as TWARC that have accumulated in storage have not yet been included in the calculations. Table 3 states estimates of exported e-waste from developed countries and Hong Kong, but owing to limited data availability, direct comparison is not possible. Considering that TWARC waste forms only a portion of the waste under Categories 1, 3 and 4 of the WEEE Directive, an annual quantity of 0.065 million tonnes of exportation from a city as small as Hong Kong is a significant quantity. There is no accurate trade statistics to show where the TWARC waste is exported from Hong Kong. However, it is generally believed that developing countries like China and India (Agarwal et al., 2003) are most affected by the recycling of e-waste imported from developed countries because of the use of old-fashioned technologies and the lack of personal protection or pollution control measures (Agarwal et al., 2003; Nnorom and Osibanjo, 2008; Sepúlveda et al., 2010). In general, exporting e-waste to developing countries has raised ethical and environmental concerns (de Oliveira et al., 2012; Shinkuma and Huong, 2009) and is not an environmentally sustainable option. Environmentally sound e-waste recycling requires the use of state-of-the-art facilities as well as skilled labour, both of which require significant investments which are not affordable to many developing world cities. For instance, in Japan an estimated US$20 million of tax money was injected into the e-waste recycling programme under the Household Appliance Recycling Law in 2005 for the recycling of televisions, washing machines, air-conditioners, and refrigerators (Yoshida and Yoshida, 2010).

3.6. Potential problems with current TWARC waste handling in Hong Kong

With the predicted increase in e-waste generation from both households and the business sector, Hong Kong faces an imminent e-waste problem owing the lack of local capacities to handle them



^ Value contains only known tonnages from proceeding input processes

* Figure projected on average of collected tonnage over identified disposal outlets

+Figure projected on average of collected tonnage over assumed disposal outlets

? No information on tonnage available

Fig. 2. Material flow of TWARC waste from Hong Kong households.

Table 3
Comparison of exported e-waste from developed countries (unless otherwise specified, figures are for household generated e-waste).

Country	Year	Type	Quantity (million tonnes)	Reference
Canada	2002	Computer	0.02[a]	Basel Action Network (BAN) (2002)
USA	2005	Cat. 1–4 of WEEE[b] Directive	1.3	Zoeteman et al. (2010)
EU-25	2005	Cat. 1–4 of WEEE[b] Directive	1.9	Zoeteman et al. (2010)
Japan	2005	Cat. 1–4 of WEEE[b] Directive	0.62	Zoeteman et al. (2010)
Hong Kong	2009	TWARC	0.065	Present study

[a] Estimate on all computer waste generated in Canada (household and other sectors).
[b] Cat. 1: Large household appliance; Cat. 2: Small household appliance; Cat.3: IT and telecommunications equipment; Cat. 4: Consumer equipment.

in an environmentally sound manner. Exportation is not a long term solution, not just because of the ethical concern mentioned above. Private e-waste collectors only accept material that is in demand in the importing countries. In the field study, it was found that e-waste recyclers no longer collect cathode ray tube (CRT) televisions larger than 21 in. because they have been replaced by LCD televisions in China. However, smaller CRT televisions may be used as reviewing monitors and are therefore still accepted by e-waste collectors. In addition, the large volume of traffic in e-waste within Hong Kong, whether generated locally or imported for re-export, is not without risk. Although primitive recycling methods such as those observed in major e-waste recycling towns such as Guiyu (China) and Delhi (India) are not known to be practiced in Hong Kong, the open burning and dismantling of e-waste on agricultural land in Hong Kong have been documented (Man et al., 2010). In 2005, the Hong Kong Environmental Protection Department identified 91 sites in the Northern New Territories involved with e-waste related activities (Legislative Council, 2005). Same with workers in the developing countries, e-waste workers in Hong Kong are often unaware of the risks involved in handling e-waste, and even if they are aware of the risks, there are often no protective and preventative measures taken. Open storage of large quantities of e-waste without proper management also poses human and environmental risks especially during accidental fires when toxic chemicals may be released (The Standard, 2008).

To solve these problems, Hong Kong Government is planning to establish a formal e-waste take-back and recycling system so that Hong Kong can handle and treat its own e-waste within its territory in an environmentally sound way. However, overseas experience and our study data show that even if a formal take-back system is established, existing informal e-waste trade will continue, albeit not in a fully legal manner. Where formal and informal recycling sectors co-exist, a major problem faced by qualified recyclers would be insufficient supplies owing to the usually lower redemption values offered to e-waste generators. This is because formal e-waste recycling plants are more often than not unable to recover the operation cost from selling the scrap materials only (Chi et al., 2011). Therefore, it is highly likely that without financial subsidy, it will be extremely difficult for formal e-waste recycling plants to operate in competition with their informal rivals in Hong Kong.

4. Conclusion

In addition to the limitations mentioned in Section 3.3, we have reasons to believe that the estimated quantities of TWARC waste handled or processed by the informal e-waste trading sector may be an underestimation. As previously mentioned, it is possible that some traders are engaging in illegal activities, such as under-reporting or do not report their revenue to the Inland Revenue Department in Hong Kong. As a result, these traders concerned may also consistently understate their throughput levels in their interviews with us. If this is the case, the figures presented in this study may be underestimations. Thus, on the whole, data quality is the highest for those collected from Consumer Disposal Pattern Survey and lower for the Private E-waste Trader Survey.

There are also policy implications from this study. First, there is an urgent need for Hong Kong Government to impose regulatory control governing e-waste treatment, not least because 65,300 tonnes/yr of TWARC wastes from households alone are currently stored and exported by private e-waste traders. Based on current situation, even if the proposed PRS is in place, no more than 40% of the locally generated TWARC waste would be properly treated. Should Hong Kong decide to assume its environmental responsibility in full to handle all the e-waste generated locally in Hong Kong, we need approximately two e-waste plants with an annual handling capacity of 30,000 tonnes/yr just to handle all TWARC waste satisfactorily.

Second, this material flow study informs the waste policy makers what routes TWARC waste will take before leaving Hong Kong and the corresponding magnitude of each route. Policy makers can then formulate appropriate measures, be it administrative, legislative or voluntary, to better engage and manage the parties involved for the purpose of achieving environmentally responsible e-waste management. For instance, since households in Hong Kong seem to favour the continued existence of the e-waste traders and the majority of household TWARC waste is currently handled by e-waste collectors, the Government should formulate policies to incorporate this party in the formal take-back system and whenever possible, provide them with incentives to operate in an efficient and environmentally responsible manner.

Although not directly related to the material flow analysis, in the course of this study, we discovered that workers in the trade were often unaware of the hazards involved and the traders were unwilling to invest in proper protection for both humans and the environment. However, this problem can be solved by defining acceptable trade practices for the waste recycling industry. This will not only protect the health of the workers but also raise their awareness of the risks to themselves and the environment. As such, the risk posed by TWARC waste treatment for Hong Kong's residents and environment can be greatly reduced.

This study was based on survey data and an average was often used in calculating the throughput of the MFA. However, it is hoped that this first attempt at gaining a deeper understanding of current trade practices and the identification of disposal outlets will assist the Government in preparing feasible and effective control measures for TWARC waste.

Acknowledgements

The authors would like to thank the team of surveyors, especially Miss Winnie Lee and Miss Carol Cheong, for their help in conducting the interviews. This research is supported by a grant from the Public Policy Research Grant (HKBU 2001-PPR-5), the Marginally-Funded Post-Graduate Fund (on Persistent Toxic Substances) from the Research Grants Council of Hong Kong, a Hong Kong Polytechnic University research project, "Cross-Border Environmental Protection Between Hong Kong and Guangdong Province" (a/c:

1-BB05) and the Hong Kong Baptist University (FRG1/08-09/037) and (FRG1/11-12/018).

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