Development of Methodology for E-Waste Estimation – A Material Flow Analysis Based SYE-Waste Model

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EXECUTIVE SUMMARY

With the improved living standards in Asian cities and the increased share of services sector to the economy, the use of electronic equipment is inevitable which essentially results in increased E-waste generation. In India, unlike in the case of municipal solid waste where the management rules are in place, E-waste management is neither regulated no streamlined so far. Peculiarity of E-waste is that it has a “significant” value even after its life time and to add complication, even after its extended life - in its “dump” stage. Thus in Indian situations, the E-material after its life time is over changes hands more than once and finally ends up either in the hands of informal recyclers or in the store rooms of urban dwellings.

This character makes it extremely difficult to estimate E-waste generation. Typical approach of “sales data” would not reveal the waste generation as there is no conversion factor from the material-to-waste. Dumping character is influenced by so many socio-economic and cultural aspects. Therefore, in order to arrive at a meaningful estimate of E-waste generation one has to go by material flow approach where a network is established from the “sale” of the E-good till its final disposal. The present study attempt to develop a functional model based on material flow analysis approach by considering all possible end-uses of the material, its transformed goods finally arriving at disposal. It considers various degrees of uses derived of the e-goods viz. primary use (life time), secondary use (first degree extension of life), third hand use (second degree extension of life), donation, retention at the respective places (without discarding), fraction shifted to scrap vendor, and the components reaching the final dump site from various end points of use.

This “generic functional model” named SYE-Waste Model developed based on material flow analysis approach can be used to derive “obsolescence factors” for various degrees of usage of E-goods and also to make a comprehensive estimation of E-waste in any city/country.

Keywords: E-Waste, Generation, Estimation, Material Flow Analysis, Obsolescence Factor

INTRODUCTION

India has been on rapid economic growth path and the past two decades of economic reforms have succeeded to have a growth rage in the range of 8.5%. Services sector had dominated the rapidly growing economy of the country (GoI, 2009). While the services sector, which is largely driven by the IT industry has resulted in increased number of electronic equipment such as

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personal computers, printers and other work related equipments, almost doubled per-capita incomes in metro cities such as Mumbai and Delhi have resulted in increased access and usage of electronic and electrical items such as mobile phones, refrigerators, air conditioners etc. Opening up of markets and also higher income levels have also resulted in higher rates of obsolescence at personal usage as well as at production level with more frequent change of models in the market. As reported by Jain and Sareen, the Indian consumer electronics industry had a size of 2.37 billion USD comprising of a colour TV market of 1.86 billion USD, with audio and other TV components taking the reminder of the share (Jain and Sareen, 2006). Dwivedy and Mittal have estimated total E-waste generation during 2007-2011 to be 2.5 Million Metric tones out of which personal computers (PC) would be about 30%.

With Indian economy expected to continue with its high-growth paths (IGIDR, 2011), and with no immediate signs of services sector being dominated by other sectors, E-waste generation both from commercial establishments as well as residential, is expected to rise over the next 10-20 years. Steepness would depend largely on the central policies on recycling. Asian region, as presented by Terazono et.al, (2006), is undergoing rapid (economic) growth and need to employ 3R principles along with other control measures, if waste management issues such as E-waste need to be address at proper time and scale (Terazono et., al., 2006).

In order for such measures (effective recycling) to develop, which are largely on a small and medium scale enterprise (SME) model, it is important to have a gauge of e-waste streams. Though there exist a number of methods of e-waste estimation (Jain and Sareen, 2006; Dwivedy and Mittal, 2010; Streicher-Porte et al., 2005), most of them fall short in comprehensively address the issue of E-waste estimation. Different end-use points add to the complication of e-waste estimation and varied consumer behavior makes it even more critical. This papers attempts to develop/augment a theoretical e-waste estimation process by employing the basis principles of material-flow analysis.

METHODS OF ESTIMATING E-WASTE – A REVIEW

Material Flow Analysis

Unlike the conventional waste (municipal solid waste) e-waste has a different end points for the same good and also the varied discarding patterns. Therefore it is difficult to assess what is the waste generation rate from any particular item of electronic gadgets. For instance, a personal computer (PC) bought would have an average life span of 5 years. However, user of PCs would show varying patterns of discarding it after its life span is over. Some may continue to use it beyond its life time; others may donate it where it is used further for some years. Some may keep in store and others may pass it on to informal recyclers where they would use the useful part for refurbished PCs and other may be subjected to material recovery and final disposal. This invariably compels researchers to adopt material flow analysis in a life cycle framework in order to estimate the generation of E-Waste.

Material flow analysis (MFA) is a process through which the complete flow of material is analyzed in a particular system. It considers life-cycle approach and is often called “cradle-to-grave” analysis. An accurate material flow analysis along with certain assumptions can give precise e-waste estimate. Often it is supplemented with other methods or relevant assumptions to estimate e-waste. And all other methods of estimating e-waste do involve material flow analysis of the electrical products as an invariable-step. Following are the other few methods used in the literature, which may in combination use MFA.

Market Supply Method

Market supply method estimates e-waste taking into account the data statistics for sales of electronic equipments and their average life period. It takes into account two critical assumptions. The first assumption is that particular equipment is discarded as waste once its life span gets over. And this method doesn’t take into account the variation in the average life period of the electronic equipment.

We consider one variant of the market supply method where we do away with the assumption of no difference in the average life span. So in this method, which is an extension of the market supply method, we allow for a substantial difference in the variance in the average life period of the electrical appliances. The variance depends on the distribution around the average life period and distribution is attained by undertaking survey of the end users.

Consumption Use Method

Consumption based method consider the data on the stock of the electronic equipment at the household sector. Then, in order to estimate the amount of electronic waste, one need to divide the stock levels by the life span (average) of the equipment. While estimating stock levels, both penetration level as well as the number of households is taken into account. One can do the similar exercise for industrial sector as well.

Government of India, in its current census (2011), is collecting information on various electronic equipments such as TV, Radio Transistor, Refrigerator, Air Conditioner etc. at household level. This data set would make it easier and feasible to conduct this type of analysis for E-Waste estimation in the year to come (Census, 2011).

Econometric Analysis

Econometric analysis takes into consideration various factors which affects the estimation of e-waste like GDP of an economy, growth rate of an economy, population of a country, etc. and then tries to estimate e-waste by employing regression tools. This method would fail to consider the heterogeneous character of consumer behavior and also the life cycle aspects of the analysis which is a key for estimating E-Waste.

Questionnaire Based Survey

Another method of estimating e-waste is a questionnaire based survey. As mentioned in the earlier sections, it is often supplemented by an MFA to complete the process of estimating e-waste. The survey could be conducted on a household basis, commercial establishment basis or even on an industrial basis. The questions are framed in such a way to collect information about the options of disposing off the electrical appliances, the average year of using an electrical product after re-using, obsolescence rate of different electrical appliances etc.

Other methods

Time step, Carnegie Mellon (which is a variant of market supply method) method, Batch leaching (which takes into account stock at particular time period) are other methods which are more or less variant of the methods mentioned above are also used to estimate e-waste.

Comparing Various Methods of Estimation

Limitation with the material flow analysis is the detailed data requirements, which are extremely difficult to fulfill. Further, the assumptions made on the end-use of electrical appliances could make a big difference in the estimate of waste generation. Estimates are distinctly sensitive to any variation in the end-use factors. However, Sensitivity analysis could be employed in a way to control this deviation. Similarly using questionnaire based survey could also lead to certain problems such as poor response rates experience in such surveys (Steubing, 2007).

In most cases each of these individual methods falls short either on their assumptions or the availability of data. Therefore, it is proposed that a combination of methods may be employed to have an effective estimate of E-waste. For instance, an attempt can be made to organize and manage the data on sales of electrical products (Market Supply Method) followed by a material flow analysis (with certain assumptions) to arrive at a reasonable degree of waste material flow in and their subsequent transformation into waste. A questionnaire survey can substantiate further, on the differentiated obsolescence rates. The present study considered such a possibility and based its model on an integrated approach of methodology. Following section presents some case studies and review of works where different methods of E-Waste estimation are employed.

ESTIMATING E-WASTE: CASE STUDIES AND REVIEW OF LITERATURE

Philippines

Considering five electrical products i.e. televisions, air conditioners, radios, refrigerators and washing machines as part of WEEE, Peralta and Fontanos have conducted a study in 2005 to estimate the level of e-waste generation in Philippines (Peralta and Fontanos, 2005). In a hybrid approach as discussed in the previous section of this paper, Peralta and Fontanos have conducted a material flow analysis or the end-of-life model and associate it with the data on domestic sales after 1985. The source of the domestic sales data of electronics was the Philippines National Statistics office (NSO) and some of the important components of E-Waste were not considered due the lack of data. Several assumptions were made on the obsolescence rates, which hold the key for the legitimacy of the result, at various stages of the material flow analysis.

Mathematical equation are derived incorporating factors such as the number of devises in use, current end of life practices, serviceable years of the product and disposal behavior of the customers. E-Waste was estimate by employing the following equations:

$R_u = 0.5\ O_j$
$S_t = 0.3\ O_j + 0.25O_{j-3}$
$R_c = 0.05O_j + 0.16O_{j-3} + 0.05O_{j-6}$
$L_a = 0.15O_j + 0.39O_{j-3} + 0.20O_{j-6}$

Where O is the number of obsolete electrical items for a particular year j
j-3 and j-6 are 3 or 6 years before the current year
R_u is the number of items reused for the year in the year j
S_t is the number of items stored for the year
R_c is the number of items recycled for the year
L_a is the number of items land filled for the year

It was estimated that around 2.7 million units would become obsolete at the end of 2005, the respective figure for units in storage was estimated to be 1.4 million units and the units that required land filling was estimated to be around 1.8 million. It was concluded that the number of units going for land filling and storage on an annual basis would be greater than 1 million units.

Delhi, India

In an effort to construct an approach and methodology to estimate future outflows of electronic waste in India, Dwivedy and Mittal have used a time series multiple lifespan end-of-life model proposed by Peralta and Fantanos for estimating the current and future quantities of E-Waste in India (Dwivedy and Mittal, 2010). Extending the model proposed by Peralta and Fantanos, Dwivedy and Mittal have considered two scenarios where the approximation of e-waste generation was based on user preferences to store or to recycle the waste. According to the estimate reported, during 2007-2011, the total WEEE estimates would be around 2.5 million metric tones which include waste from PCs, TVs, refrigerators and washing machines.

In both the studies by Peralta and Fontanos (2005) and Dwivedy and Mittal (2010), the constants used in the equations define the degree of waste estimated and there is no systematic methodology proposed for the estimation of these factors. Variation in these constants can potentially change the waste generation and it is essential to address this issue.

In another study considering only PCs and TVs within the state boundary of Delhi and in selected areas of National Capital Region (NCR), Jain and Sareen (2006), attempted to apply material flow analysis to establish an E-waste trade value chain, where cathode ray tubes (CRTs) were tracked in the E-Waste dismantling stream of CRT re-gunning process. The market supply method based theoretical estimation revealed that 2 million units of E-waste could be generated from domestic market by 2010.

The theoretical model was further augmented with a sensitivity analysis considering the life spans of PC and TVs in the range of 5-7 years and 10-12 years respectively (Jain and Sareen, 2006).

Mangalore, India

Estimation and material flow analysis of waste electrical and electronic equipment (WEEE) was conducted by Kumar and Srihari (Kumar and Srihari, 2007) for the city of Mangalore in India. Market supply method was employed to estimate the e-waste generation considering the data on average weight (kgs) and average useful life span (years) of the electronic equipments. While considering personal computers, phones, washing machines, refrigerators and televisions they had used sales data and average life period to apply market supply method.

They applied a conventional market supply method of estimate to find the E-Waste generation in Mangalore city. Further, in a method named as "Market Supply 'A' Method", they tried to give away with the assumption of "no variation in the average life span of the commodity. Consumption use method was also employed where they considered the data on stock of electronic appliances at the household level. It was interesting to notice that the estimated level of electronic waste was lower in the case of market supply method as compared to the consumption use method. Arguably consumption use based method could result in better result but generating data set could pose a major challenge.

It was estimated that in 2007, the WEEE generated in Mangalore city was about 228 tons and is expected to touch 1200 tonnes by 2010 and 3500 tonnes in 2015. This study excluded the data on imports. Throwing light on an interesting point, it was observed that only 0.23% of municipal solid waste (MSW) is in the form of WEEE.

Chile

In an integrated approach of E-Waste estimation in Chile, "Swiss Federal Institute of Technology (EPFL)" had attempted to estimate E-waste generation during the period 1994-2020. While MFA is the central approach, they had attempted to use sale data and a questionnaire survey method. This study included laptops, computer, LTDs and CRTs. MFA was used to consider various stages of the electronic equipment from its production to disposal. A questionnaire survey was conducted among households, government institutions and businesses to derive information on the use of electronic equipment, their ultimate fate, number of years for which computer is stored, the amount of the computers which are recycled and other relevant information (Steubing, 2007). This study explains the difficulties faced in this method of estimation. Out of 255 questionnaires distributed they could gather responses only from 43 respondents making it only 17% response rate. This is far low compared to standard response expectancy in questionnaire surveys. Waste generation was done on four scenarios for the period 1994-2020. Those scenarios include "from collected data", "from collected data with adjustments", "best case" and "worst case". E-Waste generation in the form of computers for the period 1996-2020 was reported to be in the range of 172 to 332 tons (Steubing, 2007).

PROPOSED MODEL FOR E-WASTE (COMPUTERS) ESTIMATION

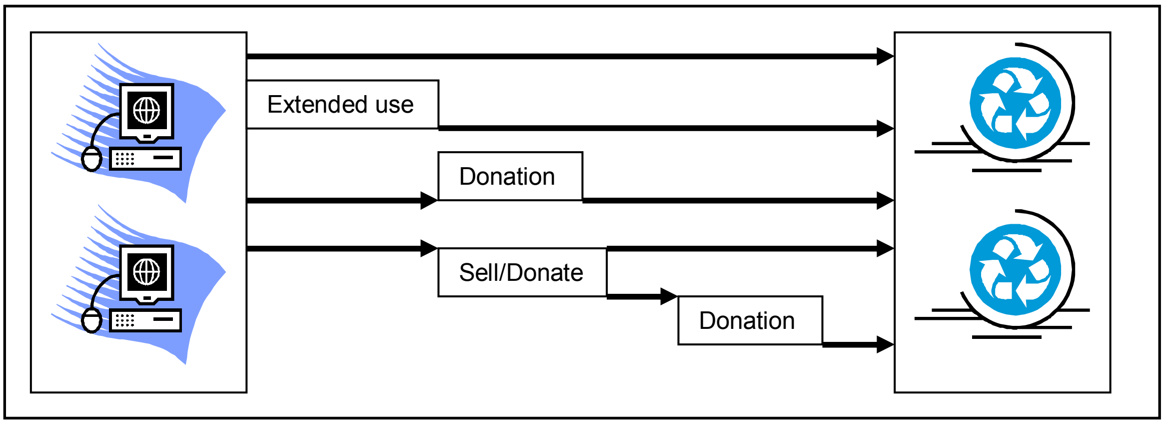
Based on the existing literature it is clear that in order to estimate electronic waste generation one has to account for the material flow and analysis how the product is moving forward in the "use-pattern" towards its end of life stage. In India, computers usually go beyond its official life span of 5 years. Following are the possible paths of a computer in Indian consumption behavior:

- Computers used for their official life span and discarded
- Computers used for their official life span and then donated for further use and then discarded after its first "reuse"

☼ Computers used for their official life span and then sold/donated to secondary use which is further donated to a charity for use and then discarded after its second "reuse"

☼ Computers used "X" years longer than official life and then discarded

Following schematic diagram of material flow presents different degrees of recycling and end-use before the product is actually subjected to dismantling, recycling and disposal. Similar schematic diagram can be developed for all other E-Waste components.



Considering all the above use-patterns the following expression is derived for the estimation of total waste generated in any particular year "t" and is named as SYE-Waste Model.

$$\sum_{i=1}^{n}\sum_{j-1}^{m} W_{ijt} = \alpha_{ij} X_{ij_{t-a}} + \beta_{ij} Y_{ij_{t-a-b}} + \gamma_{ij} Z_{ij_{t-a-c}}$$

Where W_{ijt} is the total waste generated in the year t by firm 'i' of component 'j' (computer, printer etc)

Xij_{t-a} is the number of units of product type "j" bought by firm "i" of in the year t-a

Yij_{t-a-b} is the number of units of product type "j" bought by firm "i" of in the year t-a-b

Zij_{t-a-c} is the number of units of product type "j" bought by firm "i" of in the year t-a-c

'a' is the obsolescence rate (official life span) (years)

'b' is the first hand obsolescence rate (first recycling) (years)

c is the second hand obsolescence rate (second recycling) (years)

α_{ij} is the percentage of units of product type 'j' discarded (sent for recycler/disposal) by firm 'i' each year

β_{ij} the percentage of units of product type 'j' donated by firm 'i' each year

γ_{ij} the percentage of units of product type 'j' which are used even after their life time is over

i is the number of firms/establishments from 1-n j is the number of firms/establishments from 1-m

If 'σ' is the fraction of material recovered from the E-commodities (weight), 'ρ' is the density of the e-waste, then the total waste (by weight) to be disposed is given as follows:

$$\sum W_{ij} x \rho x (1 - \sigma)$$

DATA NEEDS FOR SYE-WASTE MODEL AND CONCLUDING REMARKS

Today's waste comes from a set of purchases made in the past and based on how much time we take to actually discard it after a set of different usages (reuse etc). Data requirements for this proposed SYE-Waste model include obsolescence factors at first user, first recycler and second recycler; fraction units subjected to different usage-patterns, such as first hand use, donations, re-selling and discarding. While the procurement information on various types of electronic commodities every year can be obtained from sales information, obsolescence and usage-patterns need to be obtained by devising a simple and objective questionnaire. A sample questionnaire for this purpose is enclosed in annexure. SYE-Waste model can be applied to any city or country in order to estimate E-Waste generation subjected to the data availability.

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ANNEXURE

Indicative questionnaire that can be used to generate the data requirements for SYE-Waste Model for estimating E-Waste

Name of the organization:
Type of the organization (to cluster waste generation in to types of establishments)
Address of the Organization:
Year of establishment (to set limits on the time series data collection on sales)
Total workforce (in order to calculate waste generation per capita)

Q1: Kindly fill the following table
Remark: Chose 10 years with an assumption that maximum usage is 10 years for a computer irrespective of usage-patterns. Depending on the type of product this period could be changed

	NO. OF UNITS BOUGHT			
YEAR	DESKTOP COMPUTERS	LAPTOPS	PRINTERS	FAX MACHINES
2000				
2001				
2002				
2003				
2004				
2005				
2006				
2007				
2008				
2009				
2010				

Q2: Do you discard all the following electrical devices after their lifetime is over?
<u>Computers:</u> Yes/No <u>Laptops:</u> Yes/No <u>Printers:</u> Yes/No <u>Fax Machines:</u> Yes/No

Q3: How many of the following devices did you discard last year?
<u>Computers:</u> ____ <u>Laptops:</u> ____ <u>Printers:</u> ____ <u>Fax Machines:</u> ____

Q4: How many of the following devices did you donate last year?
<u>Computers:</u> ____ <u>Laptops:</u> ____ <u>Printers:</u> ____ <u>Fax Machines:</u> ____

Q5: How many of the following electrical devices did you retained last year for using after their life span was over?
<u>Computers:</u> ____ <u>Laptops:</u> ____ <u>Printers:</u> ____ <u>Fax Machines:</u> ____

Q3: Kindly fill in the following information:

	On an average what percentage of the following electrical devices are discarded by you each year?	On an average what percentage of the following electrical devices are donated by you each year?	On an average what percentage of the following electrical devices do you use even after their life span is over each year?	For how many extra years (after their life is over)do use the electrical devices before discarding them?
Computers				
Laptops				
Printers				
Fax machines				