Scientific Research

Material Flow Analysis of Electronic Wastes (e-Wastes) in Lagos, Nigeria

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ABSTRACT

The fate of end-of-life electronics (e-wastes) is of increasing concern because of their toxicity and ever increasing volumes. Addressing these concerns requires proper management plans and strategy which in turn requires reliable estimates of e-waste generation in the present as well as future times. In this study, a material flow model for the analysis of e-waste generation from computer equipments in Nigeria has been developed. Data used to develop the model are the sales data from major distributors of electronics, usage time of computer equipments and transfer coefficients of the electronics from one stage to another. The analysis of individual flows of computer from the material flow model showed that the fate of obsolete computer equipments were storage (41%), reuse (35%) and direct disposal (24%). The projections of the flows for a period of 15 years also indicated that storage and reuse of computer equipments would be preferred over direct disposal; and computer equipments would continue to remain in either storage, re-use or gradually disposed off for about 11 years after its inflow. This delay or staggering disposal is of advantage as it would reduce the amount of e-waste disposed yearly and also afford the country some time to make plans to accommodate and manage the e-wastes generated more efficiently.

1. Introduction

The fast growing use of Information and Communication Technology (ICT) and rapid turnover in technology is creating a growing electronic waste (e-waste) stream not only in industrialized but also in developing countries like Nigeria. The challenge is even of greater concern in Nigeria because Nigeria lacks the capacity for handling and recycling the hazardous materials contained in e-waste.

The continuous dependence on electronic equipments in homes and at workplaces as well as rapid changes in technology, changes in media (tapes, software, etc), falling prices, and planned obsolescence has resulted in a fast-growing surplus of electronic waste around the globe [1]. According to [2], the average lifespan of a new model computer has decreased from 4.5 years in 1992 to an estimated 2 years in 2005 and is further decreasing. The United Nations estimates that, collectively, the world generates 20 - 50 million tonnes of e-waste every year [3]. The minimization or elimination of these e-wastes is now of greater concern to the world at large.

The lack of capacity for handling and recycling the hazardous materials contained in e-waste usually leads to the disposal of both e-waste and municipal wastes in the same dumpsites; thereby polluting the environment with heavy metals such as Cd, Pb, Hg, and chemicals like polychlorinated dibenzo-p-dioxins (PCDDs) and furans (PCDFs), polybrominated diphenyl ethers (PBDEs) and polycyclic aromatic hydrocarbons (PAHs) thereby creating health risks to the nearby community and the population at large [4]. Thus improper management of e-wastes at the end of its useful life poses serious challenges to the existing solid waste management structures resulting in widespread contamination of the environment. Also, the e-wastes from developed countries which are exported into developing countries in the name of free trade [5] are further complicating the problems associated with e-waste management.

Nigeria is currently undergoing a rapid advancement in information and communication technology (ICT). A very significant proportion of ICT users in Nigeria rely

on secondhand equipment from developed countries, primarily from Europe and North America. The material flow of secondhand and scrap EEE into Nigeria, the current management practices for such wastes in the country and the environmental and health implications of such low-end management practices have been reviewed by [6, 7]. According to their report, the crude recycling and material recovery processes that have resulted in environmental pollution in countries like India and China which expose millions of people to toxins are yet to catch up in Nigeria. Also, a recent report by [8] on e-waste management in developing countries focusing on Africa categorized Nigeria as one of the promising countries for the introduction of pre-processing technologies if the informal sector is given strong support in capacity building through technology and knowledge exchange.

An estimated 400,000 units of second hand desktop computers (PCs or CRTs) are imported into Nigeria every month [6,7]. Meanwhile, the trading of secondhand electronics is currently booming at the famous "computer village" in Lagos, Nigeria owing to this large-scale importation of secondhand electronics. Brokers and traders from countries in the West African sub-region come to Lagos to buy secondhand computers and their accessories as well as other electronic devices. As a result, a substantial quantity of these imports may be diverted to other African countries, especially countries in the ECOWAS sub-region.

Various authors have asserted that lack of reliable data is a major challenge to e-waste estimation and management [2,9,10]. This situation is not different in Nigeria because the magnitude and flow of e-waste is not well known and the data on the local generation of e-waste and on the inflow of new electronics are scarce [6]. Hence, it is an opportune time for Nigeria to start addressing the problem of increasing e-waste volumes because neglecting the fact of growing e-waste volumes bears the risk of a developing informal sector, with all its social and environmental drawbacks.

This study is carried out in Lagos, the former capital of Nigeria due to the large inflow of electronics into the country through the state; and also because it is a trade center for computers for other West African countries. This study intends to fill the gap of the flow of e-wastes as well as determination of the fate of obsolete electronics equipments in the study area with a view to providing the information obtained to policy makers and researchers for use in drawing up management plans for e-wastes in the country.

2. Materials and Methods

2.1. Geographical Scope of Nigeria

Nigeria is situated in West Africa; Nigeria has an area of

923,768.00 sq kilometers and lies between latitude 40° and 140° North of the equator and longitudes 30° and 140° East of the Greenwich meridian. The use of ICT is more concentrated in the urban centers of the country than in the semi-urban and rural areas. In this regard, this study focuses the e-waste generation and management in one of the major urban centres in Nigeria; Lagos metropolis.

2.2. Material Flow Analysis of Obsolete Computer Equipments

The method developed at Carnegie Mellon University [11] was used for the material flow analysis in this study. Also the study of [12,13] had some influence on the choice of processes that were included in the model. These processes are the re-use and storage parameters of obsolete computer equipments which delay their entry into the waste stream.

2.3. Modeling Software

Microsoft Excel has been chosen as the modeling software mainly for the reason that it is relatively simple to use and commonly available.

2.4. The Model Input

The inputs for the model are; sales data, usage times of computer equipments and the transfer coefficients as illustrated in **Figure 1**.
- **Importation and sales data** for the goods considered in the model (desktops and laptops) constitute the inflow of the model.
- **Usage times** per process determine the time a good remains in one process.
- **Transfer coefficients** determine how a good is partitioned when more than one flow exists after a process.

2.5. Estimation Equations for the Material Flow Model

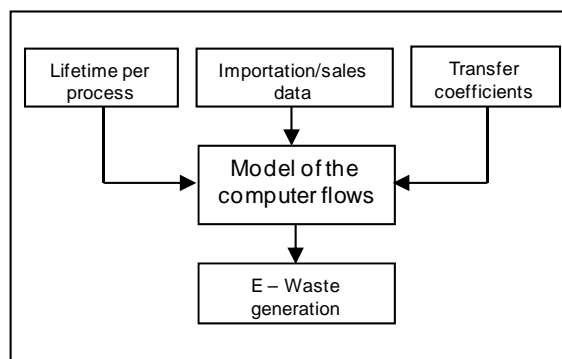**Amount in storage**: the amount of computer equipments

Figure 1. Principal data flow through the model.

in storage at a time (t) in terms of inflow of computer items is the sum of the amount stored from obsolete computers that were bought 4 years ago, the amount stored from obsolete items bought 5 years ago which are now in their second year in storage and the amount in second storage.

The amount in second storage is calculated as half of the obsolete items from re-use which is obtained as the sum half of items that was reused from the items bought 7 years ago (without 1st storage), 8 years ago (without 1st storage but in their 2nd year in 2nd storage), those bought 9 years ago (with 1st storage and in their 1st year in second storage) and 10 years ago (with 1st storage but in their second year in 2nd storage).

This is represented in Equation (1) below:

$$ST(t) = (k_{s1} * A_{t-4}) + (K_{s1} * A_{t-5}) + \alpha_1(k_r * A_{t-7}) \\ + \alpha_2(k_r * A_{t-8}) + \alpha_3(k_r * A_{t-9}) + \alpha_4(k_r * A_{t-10}) \tag{1}$$

where $ST(t)$ = total amount of obsolete computer equipments in storage in the year t.

$A_{(t)}$ = the quantity of computer equipments imported/sold for the year (t).

k_{s1} = transfer coefficient of computer flows from corporate organizations, small business and households into 1st storage.

k_r = transfer coefficient of computer flows from corporate organizations, small business and households into 1st re-use.

t = the current year.

$\alpha_1, \alpha_2, \alpha_3, \alpha_4$ = fractions or percentage that goes into re-use after first storage from computer equipments bought 7, 8, 9, and 10 years ago respectively.

Amount in Re-use: the amount of computers in re-use at a time t is obtained as the sum of the fraction of items re-used from the items bought 4 years ago (without 1st storage), 5 years ago (without 1st storage but in their second year in re-use), 6 years ago (without 1st storage but in their 3rd year in re-use) and that of fractions of items that are in re-use from 1st storage.

The amount of items that go into re-use from 1st storage is obtained as the sum of half of items re-used from items bought 6 years ago that have been stored (storage 1) for 2 years, half of obsolete items bought 7 years ago from storage 1 (which are now in their 2nd year in re-use) and half of obsolete items bought 8 years ago from storage 1 (which are now in their 3rd year in re-use).

$$Ru_{(t)} = (k_r * A_{t-4}) + (K_r * A_{t-5}) + (k_r * A_{t-6}) \\ + \beta_1(k_{s1} * A_{t-6}) + \beta_2(k_{s1} * A_{t-7}) + \beta_3(k_{s1} * A_{t-8}) \tag{2}$$

where $Ru_{(t)}$ = the total amount of computer equipments in re-use in the year t

$\beta_1, \beta_2, \beta_3$ = fractions or percentage that goes into first storage after first use from computer equipments bought 6, 7, and 8 years ago respectively.

Amount disposed: the amount of obsolete computer equipments to be disposed at a time t is obtained as the sum of obsolete items disposed after 1st use from corporate organizations, small businesses and households as well as those from 1st storage, 2nd storage and reuse. This is shown in equation 3 below.

$$Dp_{(t)} = (k_d * A_{t-4}) + (K_{s1d} * A_{t-6}) + (k_{rd} * A_{t-7}) \\ + (k_{rd} * A_{t-9}) + (k_{rs2} * A_{t-11}) \tag{3}$$

where $Dp_{(t)}$ = amount of obsolete computer equipments disposed in the current year (t).

k_d = transfer coefficient of computer flows from corporate organizations, small business and households into disposal after 1st use.

k_{s1d} = transfer coefficient of computers from 1st storage to disposal.

k_{rd} = transfer coefficient of computers from reuse to disposal.

k_{rs2} = transfer coefficient of computers from re-use to second storage.

2.6. Model Scenarios

Three scenarios were developed for the prediction of e-waste to be generated from computer equipments in the study area for the year 2011-2025. The first scenario is based on the data obtained from the present study while the second and third scenarios present the best and worst cases respectively. The best and worst case scenarios are designed to determine what could be the maximum and minimum e-waste generation from computer equipments in the study areas in the next fifteen years. The three scenarios are described as follows and summarized in **Table 1**:

Scenario 1: from collected data

This scenario is based on the data sources presented in **Tables 1** to **3**. The model inflow was based on the sales data of major distributors in the study area while the us-

Table 1. Summary of the model scenarios for computer equipments used in the model.

Scenario	Features
1: from collected data	• Data from questionnaires • Polynomial growth of computer sales
2: best case	• Longer lifespan • Re-use and storage preferred over direct disposal • Growth rate is 10% less than scenario 1
3: worst case	• Shorter lifespan • Direct disposal preferred over re-use and storage • Growth rate is 20% above that of scenario 1.

Table 2. Sales Data from 2007 to 2011 and their Projection until 2025.

Year	Desktop	Laptop	Year	Desktop	Laptop
2007	43500	50500	2017	258421	342369
2008	44000	55750	2018	301181	402779
2009	49750	67250	2019	348120	468653
2010	58750	84500	2020	399237	539992
2011	72250	106000	2021	454533	616794
2012	107299	122284	2022	514008	699061
2013	129166	155372	2023	577661	786793
2014	155212	193925	2024	645492	879988
2015	185437	237942	2025	717503	978648
2016	219840	287424			

The italic figures are the projections made assuming a polynomial trend growth.

Table 3. Usage times of computer equipments used in the processes of the model.

	Lifetime of computer equipment per process (years)	
	Desktops	Laptops
Corporate Organizations	4	4
Small Businesses	4	3
Households	4	3
Re-use	3	3
Storage after 1st use	2	2
Storage after 2nd use	2	2

age times and transfer coefficients were obtained from the questionnaires.

Scenario 2: best case

The best case assumes a longer lifespan or usage time and flows of computer equipments to storage and re-use are favoured over flows to direct disposal. Also, the growth of computer market for the specified period is assumed to be 10% less than scenario 1.

Scenario 3: worst case

The worst case scenario assumes the opposite of the best case scenario, hence, shorter lifespan for computer equipments and a preference of the flows to direct disposal as well as a growth of the computer market of 20% above that of scenario 1 were used.

3. Results and Discussion

3.1. Model Inflow Data

3.1.1. Sales Data

The sales data for desktop and laptop computers obtained

from questionnaires received from distributors/retailers from the study areas were used as inflow to the model. Five (5) years data was obtained for the year 2007-2011 from 16 distributors/retailers in Lagos metropolis. The quantities of Laptops and desktops sold within these five years by the distributors/retailers were extrapolated to 2025 using the most appropriate trend lines. The polynomial trend lines gave the best fit ($R^2 = 0.999$) for laptop and desktop growth in Lagos as shown in **Figure 2** and the actual values given in **Table 2**.

3.1.2. Usage Times

The usage times of computer equipments in the individual processes of the model was obtained from the questionnaires administered to consumers of computer equipments (**Table 3**). However, sufficient data was not available on the storage times of computer equipments after re-use, therefore it was estimated that storage after reuse is 2 years.

3.1.3. Transfer Coefficients

The transfer coefficients (**Table 4**) were also obtained from the information compiled from the questionnaires. The transfer coefficients of computer equipments from sales to the consumers (*i.e.* corporate organizations, small businesses and households) were obtained from the information gathered from the distributors on percentage of their sales to each of the three consumer groups while the transfer coefficients from each of the consumers to 1st storage, re-use and disposals were deduced from the questionnaires issued to the consumers. There is however insufficient information on the fate of equipments after re-use and second storage. It was therefore estimated that half (50%) of computer equipments are disposed after reuse while the other half is stored further (2nd storage). It was also assumed that all (100%) of computer items are disposed after second storage.
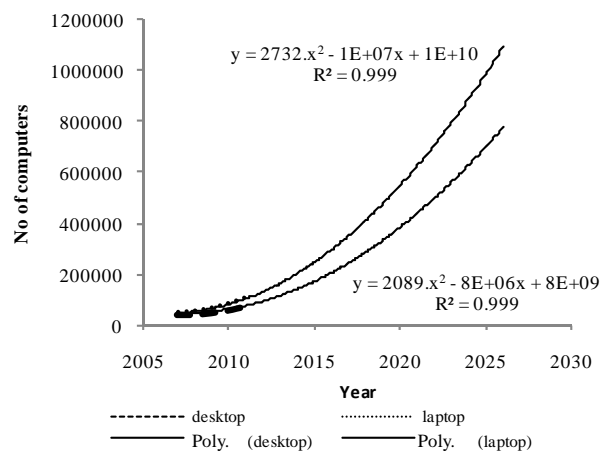

Figure 2. Extrapolation of the sales data obtained from distributors/retailers in the study area using polynomial trend.

Table 4. Transfer coefficients.

Transfer coefficients for computer equipments used in the model				
From	**To**	**Desktops**	**Laptops**	**Adjusted Average**
Importation/ sales	Corporate organizations Small Businesses Households	25% 35% 40%	20% 35% 45%	25% 35% 40%
Corporate organizations	Storage after 1st use Re-use Disposal	65.3% 26.5% 8.1%	52.7% 34.5% 12.7%	60% 30% 10%
Small Businesses	Storage after 1st use Re-use Disposal	39.7% 34.5% 25.8%	41.8% 30.9% 27.3%	40% 30% 30%
Households	Storage after 1st use Re-use Disposal	37.7% 32.1% 30.2%	24.5% 46.9% 28.6%	30% 40% 30%
Storage after 1st use	Re-use Disposal	50% 50%	50% 50%	50% 50%
Re-use	Storage after 2nd use Disposal	50% 50%	50% 50%	50% 50%
Storage after 2nd use	Disposal	100%	100%	100%

Table 5. Fate of obsolete computer equipments after 1st use from the MFA.

Fate of computer equipment after 1st use	Percentage
Storage	41%
Reuse	35%
Disposal	24%

3.2. Analysis of Individual Flows

The individual flows for each year was analyzed in order to determine the quantity of flows to storage, re-use and direct disposal after 1st use as illustrated in **Figure 3**. The summary of the flows from the consumption phase after 1st use as shown in **Table 5** below indicates that the most important flows are to storage (41%) and reuse (35%) while the flows to disposal is comparatively lower (24%). This is consistent with similar works from developing countries [14-16] where storage is the major means of managing e-wastes due to lack of take back systems. In Nigeria, this pattern of flow can be attributed to the reluctance of consumers to dispose off their out of use electronics because of the high cost of electronic equipments and hope that it could be repaired or reused somehow in the future.

The results of the material flow analysis showing the quantities of computer equipments to be stored, reused and disposed in Lagos from 2007-2036 are as given in **Table 6**.

The results indicate that the quantity of computers that moves into storage, reuse and disposal increased proportionately with the demand (sales) of computer equipments (as illustrated in **Table 2**). The quantity of computer equipments to be stored and reused in Lagos from 2012-2036 was observed to be almost equal and much higher than those for disposal.

The table also shows that quantities of computers in storage, reuse as well as those to be disposed continue to increase until four years after the last inflow (*i.e.*

2025-2029) after which their values start to drop (due to lack of inflow). The result also indicated that computer equipments continue to remain in either storage, re-use or gradually disposed off for 10, 8 and 11 years respectively after its inflow into the consumption phase. The additional lifespan of computer equipments in storage and reuse delay and reduce the quantity that is eventually disposed off yearly.

Scenario Comparison

The scenario analysis of e-waste generation from computer equipments (desktops and laptops) sold in Lagos as obtained from questionnaires and forecasted from 2012-2025 is presented in **Figure 4**. The result shows that the present scenario (scenario 1) is quite similar to the best case scenario (scenario 2) which suggests that the current e-waste management situation in Lagos is such that allows a relatively minimal amount of e-wastes to be disposed directly into dumpsites or landfills. This could be attributed to the fact that trade in secondhand computers and computer parts are well established in Lagos, hence most of the parts are reused in cloning new ones or sold to recyclers. However this is most likely to be peculiar to Lagos alone, other parts of the country where the trade is not well established may face the risk of having a scenario whereby a higher rate of disposal may be experienced.

Also the graph shows that the implication of computers having shorter life spans (as in scenario 3) is increase in the rate and quantity of e-waste generation.

For a country like Nigeria where recycling facilities for e-wastes are not yet available, storage and reuse of obsolete electronic equipments should be encouraged because e-waste disposal would be delayed and disposed off gradually. This will afford the country the time to make plans to accommodate and manage the e-wastes to be disposed off more efficiently rather than having scenario whereby a large quantity of e-waste is disposed in a relatively shorter time.

4. Conclusion

This study has shown that the demand for electronics equipments and ultimately, the quantity of e-wastes generated will continue to increase in Nigeria as it is shown by the growth trend in the sales of computer equipments.
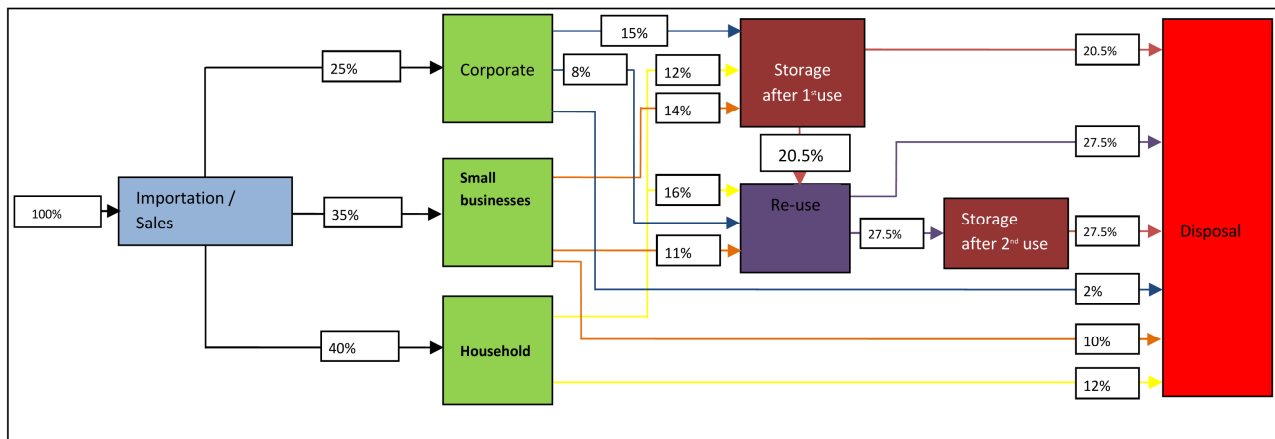
Figure 3. Analysis of individual flows of computers in Lagos.

Table 6. Quantity of computer equipments to be stored, reused and disposed from 2011-2036.

| Year			Quantity disposed		Quantity in reuse		Quantity in storage	
			Desktop	Laptop	Desktop	Laptop	Desktop	Laptop
2007	43500	50500	0	0	0	0	0	0
2008	44000	55750	0	0	0	0	0	0
2009	49750	67250	0	0	0	0	0	0
2010	58750	84500	0	0	0	0	0	0
2011	72250	106000	9896	11489	11854	13761	17835	20705
2012	107299	122284	10010	12683	23844	28953	35875	43563
2013	129166	155372	11318	15299	46318	57631	38438	50430
2014	155212	193925	19293	26104	59494	78325	50412	69098
2015	185437	237942	20947	29829	77391	105804	65632	92582
2016	219840	287424	35437	41593	96199	127771	92315	117236
2017	258421	342369	41402	51604	121179	157385	123656	148992
2018	301181	402779	55422	71026	155584	192627	147217	185926
2019	348120	468653	67185	85775	191311	238672	178913	228845
2020	399237	539992	79876	104920	233027	292681	216230	279186
2021	454533	616794	97324	125941	277170	356842	259297	336910
2022	514008	699061	114969	151633	327298	428830	308069	402183
2023	577661	786793	137498	179163	383412	508647	360179	476460
2024	645492	879988	160179	211530	445513	596290	417993	558196
2025	717503	978648	185378	247189	513598	691762	481511	647390
2026	0	0	213095	286141	587670	795060	550732	744043
2027	0	0	243329	328385	667728	906187	625657	848155
2028	0	0	276080	373921	753771	1025141	706286	959725
2029	0	0	311350	422749	845800	1151922	792619	1078754
2030	0	0	168572	228539	727534	991476	559242	761306
2031	0	0	190593	259020	593354	808995	298618	406384
2032	0	0	214180	291550	279414	381020	334448	455687
2033	0	0	157982	215146	147088	200623	264414	360440
2034	0	0	176466	240541	0	0	185708	253239
2035	0	0	87948	119898	0	0	97760	133341
2036	0	0	97760	133341	0	0	0	0

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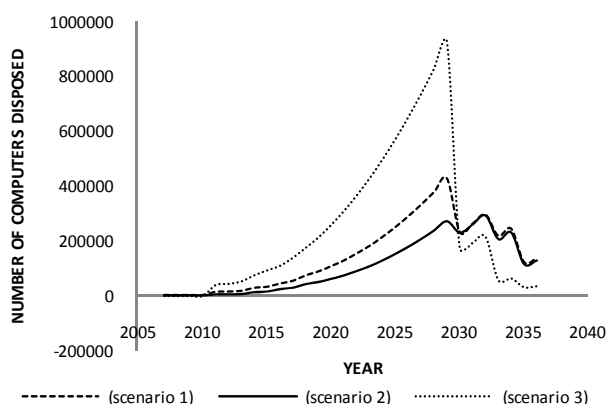
Figure 4. Estimates of E-waste generation from computers in Lagos for scenarios 1-3.

The material flow analysis of computer equipment in Lagos has storage, re-use and direct disposal as end of life options for obsolete equipments, however, the choice for storage and re-use outweigh direct disposal for economic reasons. This current practice of storage and reuse of obsolete electronic equipments give the country the opportunity to plan ahead for the establishment of proper take back programmes, recycling centers as well as other necessary schemes to tackle the problem of e-wastes in Nigeria.

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