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ELECTRONIC WASTE: THE PAINS AND THE GAINS

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Abstract: This paper presents an assessment of e-waste with respect to rate of generation, composition, risk and recycling potential. Data were extracted from published works and further analysed to provide insight into these aspects of e-waste management. Results showed that Nigeria has one of the highest per capita rate of e-waste generation (7kg/capita/year) as a result of heavy reliance on used electrical and electronic equipment as well as export of e-waste by developed countries. Television sets and personal computers constitute 55% of the total e-waste generated. Lead and copper present very high risk because of their wide application in printed circuit boards (PCB) which are used in virtually all electrical and electronic equipment and cathode ray tubes of television sets and personal computer monitors. Other metals found in e-waste include mercury, cadmium and arsenic have been implicated in severe health problems such as cancer, lung disease, renal failure and brain damage. This paper further revealed that the risk associated with improper disposal of e-waste can be reduced by recycling and re-use. E-waste from mobile phone alone has an economic potential of £186,000,000 or ₦89,000,000,000 which is equivalent to 4,886,550 barrels of crude oil. Gold component of mobile phone account for 68% of this potential revenue.
Keywords: Electronic waste, Generation, composition, management, countries, information communication

1. INTRODUCTION

Waste management is one of the most daunting challenges facing many developing countries. Research has revealed that more than 40% of solid waste generated in Nigeria goes uncollected. However, the challenge posed by municipal solid waste has been aggravated by technological advancements in information communication and technology. E-waste belong to the category of municipal solid waste resulting from used electrical and electronic equipment. It is also called waste electrical and electronic equipment (WEEE). The main challenge posed by WEEE is that they are largely inorganic and therefore non-biodegradable in nature. In addition, they are not amenable to waste reduction mechanisms such as compaction, shredding and grinding which help to ease handling, reduce hauling cost and conserve landfill space. Prominent among this type of waste are personal computers, television sets, mobile phones, rechargeable lamps, DVD players, decoders, printers and batteries. Electronic industry is the world largest and innovation industry for its kind. Every year tons of electronic equipment is shipped over oceans to the developing countries. However, after these usage time they are become a complex waste matter which consist of many hazardous heavy metals, acids, toxic chemicals and non-degradable plastics. Many are dumped burnt or exported to recyclers. However, about 75% of e-waste are uncertain for their use or finding ways to use them which includes refurbishment, re-manufacture and reuse their parts for repair etc. While others are join occupying usable space at houses, apartments, firms and industries. Most e-waste collectors import these toxic materials such as leaded glass circuit boards and mercury lamps usually from China to Africa.

Dismantling process takes much labour which is not only involve in unscrewing but also shredding, tearing and burning. The smoke and dust particle consists of carcinogenic and other hazardous chemicals which causes severe inflammations and lessions including many respiratory and skin diseases. Circuits are burnt to hunt the valuable metals such as gold, platinum, cadmium but the wire waste of those consists of PVC and PCB which may produce erotic smoke, and carborn particles from the toners and carcinogens, they may lead to lung and skin cancer (Kevin *et al,* 2008). Outside the developing nations, most developed countries of the world such as Guangzhou in China still risking their health with e-waste full of used computers, and television sets. According to data received in 2007 about 70% of e-waste of the world reach China and the rest to Africa and India, due to their cheap labour they have become the world's dumping station of e-waste, in Ghana and Nigeria about 20% of their population are working on e-waste, they use after reconditioning them (Based Action uploaded on 2013) poverty is the main reason for third world countries consume e-wastes from Europe and USA.

2. METHODOLOGY

This research work is based on literature review from green peace technical paper 10, 2008 and different research papers including video documentaries to figure out the following issues regarding e-wastes sources, dismantlers, collection, current methods of e-waste disposal, and the hazardous chemicals, heavy metals, their effects on human health and the environment, possible solutions and organization involved.

3. RESULTS / DISCUSSION

3.1 SOURCES OF E-WASTE

Almost every used electronic equipment are considered as e-waste such as discarded cellphones, cameras, CD players, TVs, radios, drillers, fax machines, photocopiers, printers toners, ink, cartridges, batteries, chargeable batteries, digital calculators and CRT monitors, electric solders, computer motherboard, keyboard, industrial and household electronic, machinery such as oven, fridge, sewing and washing machines, fan, air conditioner, grinder, iron, heater, military and laboratory electronic equipment, etc.

3.2 E-WASTE CATEGORIES

In this technological boom, both developing and developed are using EEEs in abundance in commercial, industrial and household sectors. The manufacturers are introducing new technologies as per day user demand in the equipments and obsolete the existing equipments, which are not only out featured but not compatible to the new technological requirements. This process accumulated a huge quantity of e-waste comprising numerous equipments small and large in size viz. washing machines, vacuum cleaner, VCR, Television, halogen lamps, electric Shaw, sports equipment, medical devices, monitoring and control equipments etc.

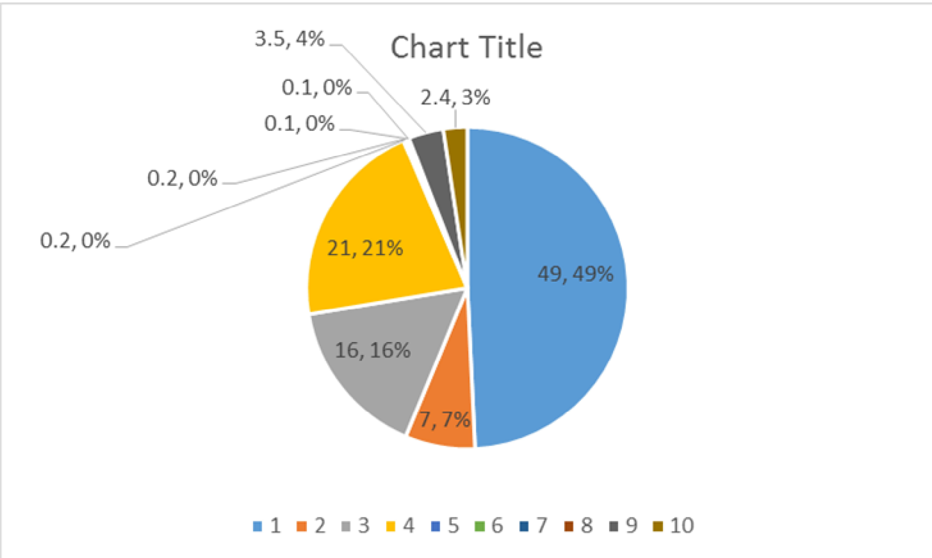

Fig. 1. Average Compositional Breakdown of E-waste.

Ref:- Association of Plastics Manufacturer in Europe(APME): Plastics — Insight into Consumption and Recovery in Western Europe 2000, cited in International Copper Study Group, 2003).

The equipment construction and usage are almost similar world over. After EOL (End of Life), obsoleting, these equipments are put in TSDF (Treatment Storage, Disposal Facility).

The participation of each equipment in e-waste has been ensured by EU Directives so that their treatment may be planed as per their composition of material and size. The equipments in e-waste are made of both hazardous and non-hazardous substances. In hazardous substances it has various toxic and hazardous substances like heavy metals lead, mercury, cadmium and persistent organic compounds BFRs, and phthalates etc. in their components which are cause of concern as they releases while processing, recycling or disposal in uncontrolled condition and pose risk on human health [UNEP 2005]. The pollutants in the e-waste are estimated as 2.7% of the total by weight [Empa,Swiss Federal Laboratories for materials testing and research]. These constituents made it a complex waste as these are present in the material in hidden form such as mercury in switches, and it is very difficult to separate them in pure form from the waste. For their proper regulation and management of all equipment for disposal- recycling, recovery, EU has categorized them in ten categories with their respective contributed percentage in the e-waste generated in EU 27[Huismann et al.2007]. The least contribution is Medical devices i.e. 01%. In EEEs manufacturing more than thousand materials are used. However the schedule 1 has categorized e-waste in two categories viz IT and Telecommunication Equipment and Consumer Electrical and Electronics. IT and Telecommunication covers Centralized data processing: Mainframes, Minicomputers, Personal computing: Personal Computers (CPU with input and output devices)Laptop (CPU with input and output devices) Notebook, Notepad etc., Printers including cartridges Copying equipment Electrical and electronic typewriters Pocket and desk calculators and other products and equipment for the collection, storage, processing, presentation or communication of information by electronic means User terminals and systems ,Facsimile, Telex, Telephones, Pay telephones, Cordless telephones, Cellular telephones, Answering systems, And other products or equipment of transmitting sound, images or other information by telecommunications and in consumer electrical and electronics: Television sets (incl LCD, LED) Refrigerator, washing machine and air conditioners[Modified Draft Notification, the e-waste ((Management and Handling) Rules 2010 was published by the Government of India in the Ministry of Environment and Forests vide number S.O.1125 (E), dated 14thMay, 2010]. The composition of these constituents will be described in section 2.

3.3 COMPOSITION OF MATERIALS IN E-WASTE

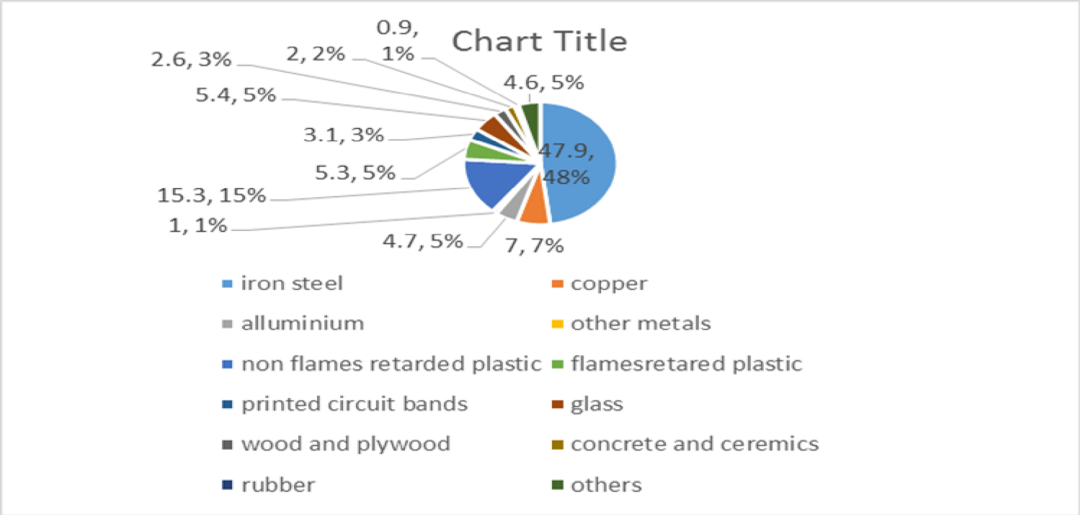

Fig 2: Weighted parameters in E-waste

The most of the Electrical and electronic equipment are manufactured with the due control by PCBs which regulates the function of the equipment. However, various other parts are used in the manufacturing. With this e-waste has become a diverse and complex nature of waste having both hazardous and non-hazardous ingredients. Broadly e-waste may be classified in weightage proportions of materials recovered from the e-waste. Steel constitutes 50%, copper, aluminium and other metals 13% and plastics 21% [ETC/SCP], however e-waste is made of wide variety of substances in thousands. The hazardous and toxic metals constitute about 1% of the total weight and rest of the material like precious metals constitute gold 0.1%, Silver 0.2% and palladium 0.005% respectively. The recoverable precious metals play a pivotal role as it gives 95% financial support to the recycling infrastructure, however other metals and materials like lead, nickel and various plastics may worth after recovery from e waste[He et al. 2006, Cui and Zhang 2008]. The availability of recoverable material made e-waste a resourceful of metals and materials. However, similar kind of study conducted by Empa (Swiss Federal Laboratories for materials testing and research) reveals that all metals constitute 60.2%, Plastics 15.2%, Metal-plastic mixture5%, Printed Circuit Boards 1.7%, pollutants 2.7% etc. as shown in figure 3.

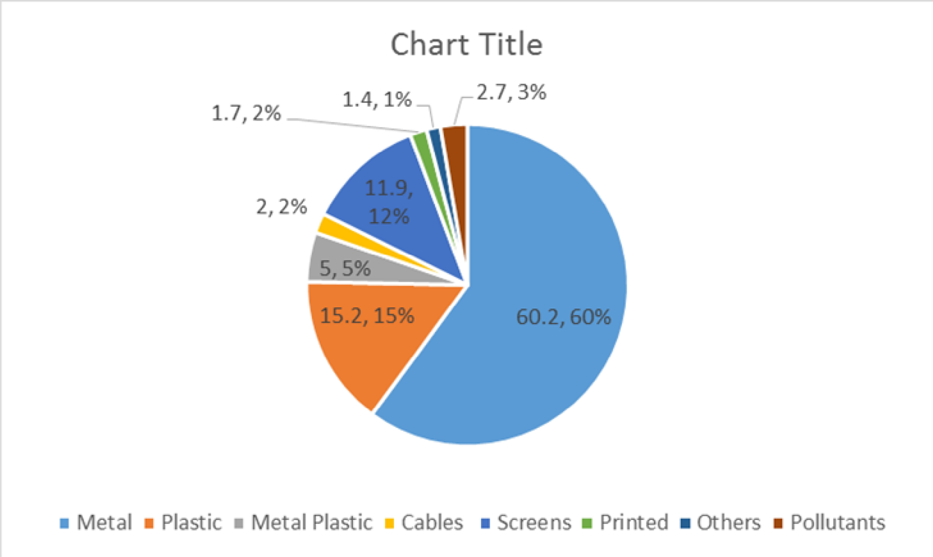

Fig 3: Average composition of Materials found in E-Waste

3.4 HAZARDOUS COMPONENTS AND COMPOUNDS IN E-WASTE

The presence of heavy metals in e-waste made it indifferent to the municipal biodegradable waste as they not only hamper the bio-degradation process but harms the human health and environment also. People engaged in the-waste treatment process are directly exposed to these metals while doing recycling, recovery processes and are most affected. However, beyond threshold value these are toxic and hazardous, for example dibutyl phthalate anddiethylhexy1 phthalate are considered “Toxic for Reproduction” at concentrations >=0.5%.[CPCB Guidelines 2008.]. Hazardous compounds are found in the components described in WEEE Directives Annex II, which are to be removed immediately from the e-wasted equipments[European Commission 2003a]. Mostly, these components are always available in e-waste [AEA 2004, EPS Canada 2006, and IGES 2009] and cause of concern of hazardousness in equipments. For example Capacitors containing polychlorinated biphenyls (PCBs), Mercury-containing components such as switches or backlighting lamps, Batteries, PC-boards of mobile phones and of other devices if the surface area of the circuit board is greater than 10 cm2 .The percentage of heavy metals depends upon the manufacturing requirements of the equipment, for example The copper traces are woven in layers in PC-board to facilitates the flow of current [AEA 2004, Eswaraiah et al 2008, IGES 2009]. The components connected in this circuitry arrangement are switches, resistors, capacitors. The connecting media is soldering having tin and lead in the ratio of 60/40 [Geibig&Socolof 2005]. The typical solder content in scrap of PC board ranges between 4 to 6% by weight or 50 g/ m 2 of PC board [AEA 2004]. However, the solder contains other different substances also. Similarly, relay and switches often contain mercury but also contain small amount of cadmium for plated contacts. All components in e-wasted equipment are not hazardous. The table 2 will show the hazardous components with respective hazardous compound used and applications of the equipment. The presence of all materials in equipment is in proportion to meet the designed perimeters. The construction of majority of equipment are PCB based which contains maximum numbers of hazardous compounds like lead, Stibium, Cadmium, mercury, beryllium, Gallium, Arsenic, and BFRs. However, OEMs are reducing these hazardous compounds in their manufacturing of equipments under the instruction of RoHS.

3.5 E-WASTE IN GHANA, AFRICA ABOUT

4 million tons of wastes are brought to Ghana from Antwerp and other parts of western world. Government of Ghana has signed in every international treaties but entry of e-waste is still there as the people of Ghana are not afford to purchase new electronic goods due to their poverty. And slum children and young men are used as collectors and dismantlers for cheap labor. E-wastes includes camera, computers, TVs, refrigerators, drillers and many used electronic items. They are sold for cheap price but no warranty for its usage, while unusable items are burned and dumped there (Figure 1). The river has now become a dark muddy stream rich in heavy metal wastes. Fisher men have almost lost their hopes and catch contains heavy metals which can cause long-term impact to human beings. (Dateline uploaded on, 2011).

3.6 CURRENT DISPOSAL METHODS OF E-WASTE

Currently following methods are used to get rid of e-wastes they are Incineration, Acid baths, Landfills

3.6.1 Landfills

E-wastes ending up as landfills are described as toxic time bomb. They may release to the environment after several years by natural means, and there is a possibility of leaching of wastes such as batteries releases acids and heavy metals mercury, nickel and cadmium, electronic circuits have lead, zinc, Nickel, Copper, Mercury and cadmium. These may reach the land water and reaches animals and humans, and mixes with other fresh water sources such as rivers and streams. Almost half the e-wastes of US and Australia are dumped as landfills while the rest are exported to Asia and Africa.

3.6.2 Acid Baths

Acid bath method is used to extract Copper, here the circuit board is submerged in to Sulfuric acid for about 12 hours to dissolve Copper then solution is boiled, precipitated Copper Sulfate is taken and remaining solution is added with scraped particles, subsequently Copper smudges are removed. Acid baths also used to dissolve the lead and in the extraction of Gold and Silver.

3.7. SAFE METHODS FOR DISPOSAL OF E-WASTE AND MANAGING AUTHORITIES

Most safe method is recycling materials including metals and reusing them, which includes industry wide system for the collection of e-wastes. Implementing proper rules to make following as mandatory wearing protective masks and gloves and safety glass when dismantling and avoid easy methods of extraction such as incineration which results harmful fumes, avoid dumping and avoid using acid baths, and implementing strict rules against dumping e-wastes in landfills as it could leach out towards ground water or may be released after long time. Implementing proper storage system for collected and extracted e-wastes until it is reused as products, strengthen the implementation of agreed legislations of Basel convention and implementing potent laws to prevent political invasions or pressures. Take action against unapproved illegal e-waste collectors and dismantlers, encourage research scientists in finding alternatives to hazardous chemicals and carcinogens, banning the electronic products with hazardous ingredients, monitoring the transportation of e-wastes within the state municipal limits as well as ports and harbors. Consulting with manufactures e-waste processors, environmental groups such as NRDC, Basel Action Network (BAN) have created a certification system for recycling, refining and refurbishing companies known as e- Stewards. E-steward certification assures the recyclers keep up the standards which allow the recycling process in a way that protects workers health and the environment. BAN also maintains a list of companies which are permitted to act as subscribed e-stewards (NRDC 2012), in 2010 the first certified standard was announced. And NRDC, BAN and other advocates are currently working on ensuring the strong implementation of the laws against e-waste exporters (NRDC 2012). Moreover, In many states of US have implemented the system to make electronic manufactures to take responsibility for their products, Thus, electronic manufactures are given great responsibility to collecting the products after their use and recycling them. It is also important to educate the public on handling and disposal of e-waste through awareness programs. It is confirmed that the public awareness and cooperation of manufactures are essential for the advancement of e-waste management system. And also it is the responsibility of governments to allocate sufficient grants and protecting the internationally agreed environmental legislations within their borders. Licensing of certification like estewardship may ensure the security to prevent illegal smugglers and handlers of e-waste. Basel Action Network is now working at their best to stop or control trans boundary e-waste movements, they also involved in conducting public awareness programs to enlighten the world community and opening research areas to find better methods or alternatives. As e-wastes are the known major source of heavy metals, hazardous chemicals and carcinogens, certainly diseases related to skin, respiratory, intestinal, immune, and endocrine and nervous systems including cancers can be prevented by proper management and disposal of e-waste.

3.8 RATE OF E-WASTE GENERATION

The world's total volume of solid waste is 1.3 billion tonnes/year. Forty million tonnes of e-waste are generated annually worldwide, accounting for between 5 and 8% of all solid waste. (Veit and Bernardes, 2015). It has also been reported that 2 to 5% of all landfilled waste is e-waste comprising of computers, mobile phones and tv sets (Veit and Bernardes, 2015). The EU and USA have the highest per capita rate of e-waste generation of 15kg/year and 7.5kg/year respectively. Surprisingly, sub-Saharan African countries such as Nigeria and Ghana have per capita e-waste generation rates of 7kg/year and 4.5kg/year respectively which are much higher than those of China and Brazil with rates of 0.2kg/year and 0.45kg/year as shown in Figure One possible reason for this is because of the high dependence of these African countries on used electrical and electronic equipment (EEE) imported from developed countries. Nnorom et al (2010) reported that 400,000 used computers are imported into Nigeria annually. Unfortunately, a large proportion of these used EEE is actually e-waste. Adaramola et al (2012) reported that 75 to 80% of all e-waste export from developed countries end up in Asia and Africa.

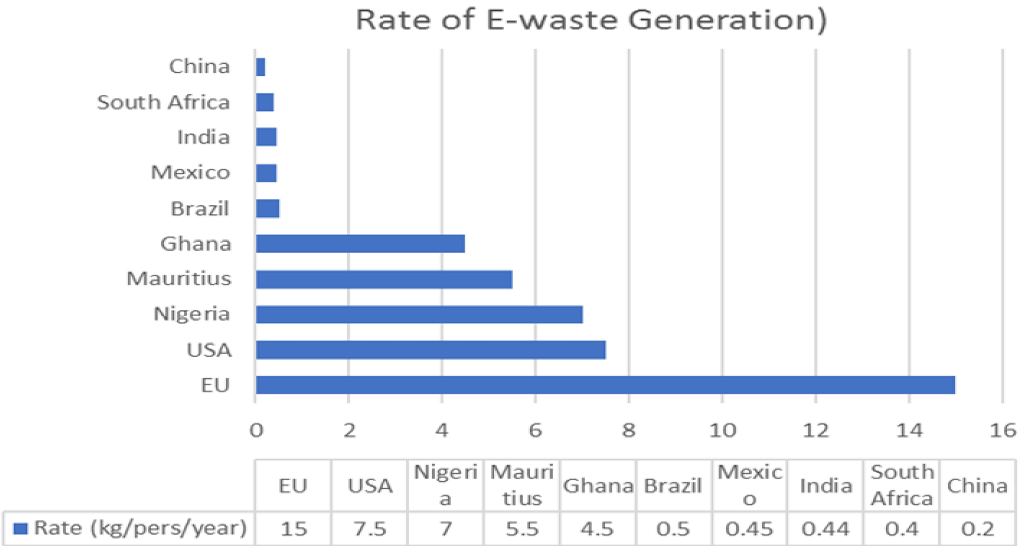

Fig 4: Rate of WEEE Generation in Various Countries

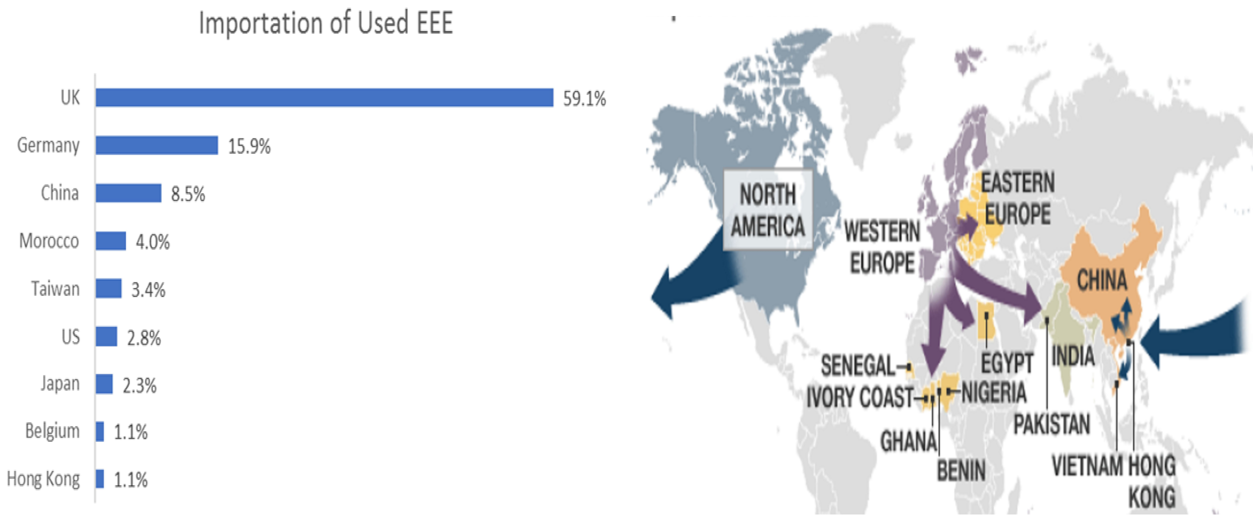

Fig. 5: Flow of Used and Waste Electrical and Electronic Equipment

Figure 2 shows that 60% of used EEE arrive Nigeria from the UK while 16% arrive from Germany. Other countries from which used EEE is imported include China, Taiwan, USA, Japan and Hong Kong. Besides, used EEE have very short life span, thus leading to increased rate of e-waste generation. One very important factor that determine that rate of e-waste generation is the life cycle of the product. Mobile phones and their accessories are among the EEE devices with the shortest life span (2 years) and hence constitute a large chunk of e-waste. Veit and Bernardes (2015) noted that 125 million mobile phones amounting to 65,000 tonnes of e-waste are discarded annually.

3.9 COMPOSITION OF E-WASTE

The composition of any waste stream is a major determinant of management approach to adopt as well as the environmental impact. Jayapradha (2015) reported that Fe, Al, plastics and glass constitute 80% of e-waste. Specifically, ferrous metals, plastics, Al, Cu and Pb constitute 43%, 19%, 14% and 2% of e-waste respectively. Overall, personal computers and tv sets constitute approximately 55% of e-waste (EEA, 2002). The rate of generation of e-waste from EEE is a function of coverage and life span. Devices with shorter life span constitute potential sources of large quantities of e-waste. Mobile phones and personal computers belong to this category. Table 1 shows the life span of certain EEE devices. With Nigeria currently at 77.5% mobile phone coverage (penetration), the volume of e-waste is expected to grow exponentially. This value is greater than 63.2%, 53.2% and 28% coverage in Kenya, Ghana and Sri Lanka respectively. Figure 3 shows the typical composition of a mobile phone.

Table 2: Particulars of Some Electrical and Electronic Equipment

Equipment	Life Span	Major Constituents
Mobile Phones	2	Cd, Ni, Zn, Cu, Hg, Au, BFR, plastics
Printers	1 to 8	
Fridge	15 to 20	CFC, HCF
TV	15 to 20	Cu, Fe, Al, Pb, Al, Cr, Ag
Washing Machine	15 to 20	
Personal Computer	2 to 5	Cu, Al, Fe, Ni, Pb, Ag, Au, Plastics, Rubber
Photocopier	5 to 10	Ferric oxide, Cadmium sulphide
AC	5 to 15	
Batteries		Ni, Pb, Li, Zn, Si, Sn, Sb, Mn

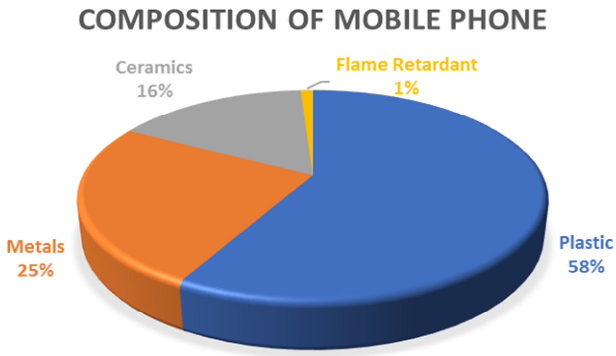

Fig. 6: Typical Composition of Mobile Phones

3.10 RISK ASSOCIATED WITH E-WASTE

It has been earlier stated that the major challenge associated with e-waste is the non-biodegradability of its components. Most of these components constitute serious environmental and health hazards. Unfortunately, most of the e-waste generated in developing countries are improperly disposed, resulting in the accumulation of associated toxins in the environment in concentrations that are harmful to plants and animals, humans included. Table 1 shows the contaminants found in different components of mobile phones. The printed circuit board has the highest concentration of metallic contaminants. The cathode ray tube (CRT) of a monitor accounts for 50 to 62% of the weight of the monitor and contains 8 to 20% by weight of lead of approximately 0.68 to 2.72kg (Nnorom et al, 2010).

Table 3: Contaminants in Major Components of a Mobile Phone

Component	Function	Contaminants
Printed circuit board (PCB)	Allows circuit components to transfer information and signals between each other as well as information to external devices	Cu, Au, As, Be, Br, Cd, Pb, Ni, Pd, Sb,Ag, Zn, Ta
Liquid crystal display (LCD)	Used for visual display	Hg
Battery	Provision of power	Cd, Ni, Zn, Cu
Charger	Battery charging	Cu, Au, Cd, BFR
Casing	Protection and beautification	Polycarbonate (PC) acrylonitrile butadiene styrene (ABS)

Specifically, the CRT of computer contains 8% by weight of Pb, Ba, Cd, Cr, Cu and Zn (Olubanjo et al, 2015). Olubanjo et al (2015) investigated the preponderance of Cu and Pb in the printed circuit boards of computer CPU, CRT and monitor and found that CPU had the highest amount of Pb (89.88g/kg) and Cu (376.196g/kg). Typically, PCB contains 16% by weight of Cu, 4 to 6% of solder (Pb and Sn), 2% of Ni and 0.002% of Hg. These metals have been found to be very toxic and lethal even in trance quantities. Figure 4 shows a risk chart of selected e-waste components. Lead, mercury and cadmium cause renal failure, cadmium and arsenic cause cancer, mercury, beryllium and arsenic cause lung disease while lead causes brain damage. Burning of e-waste releases dioxins and furans which are cancerous (Cherutich, 2013)

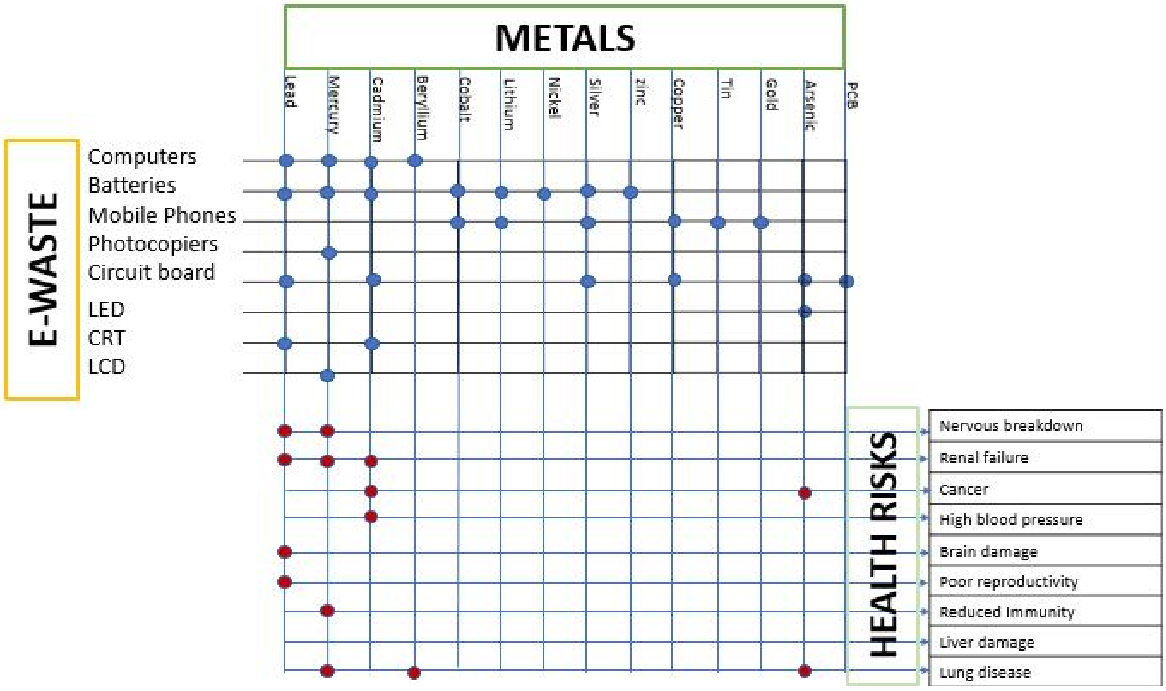

Fig. 7: Health Risk Chart of Selected E-waste

3.11 RECYCLING: TURNING WASTE TO WEALTH

The ultimate goal of best waste management practices is elimination of waste. However, this has proven elusive and the best that can be achieved is waste minimization. It has been reported that over 90% of e-waste in developing countries end up in landfills. Conversely Japan recycles 75% of e-waste generated while EU, USA and India recycle 35%, 25% and 27% respectively (Figure 7). Waste minimization can be achieved by recycling and reuse of waste products. Recycling integrates the concept of sustainability into waste management by engendering resource recovery, resources conservation and revenue generation. Most EEE contain reasonable amount of precious metals. Veit and Bernardes (2015) observed that one mobile phone contains 24mg of gold, 250mg of silver, 9mg of palladium and 9g of copper. Cherutich (2013) reported that 65% to 80% of mobile phones can be recycled. Table 3 shows that e-waste has enormous potential for revenue generation. For instance, with respect to mobile phones, gold holds 64% of the total potential revenue, while silver, palladium and copper have 13%, 14% and 9% respectively (Table 3). This translates to £1.1 or ₦534 per mobile phone in terms of these four metals only.

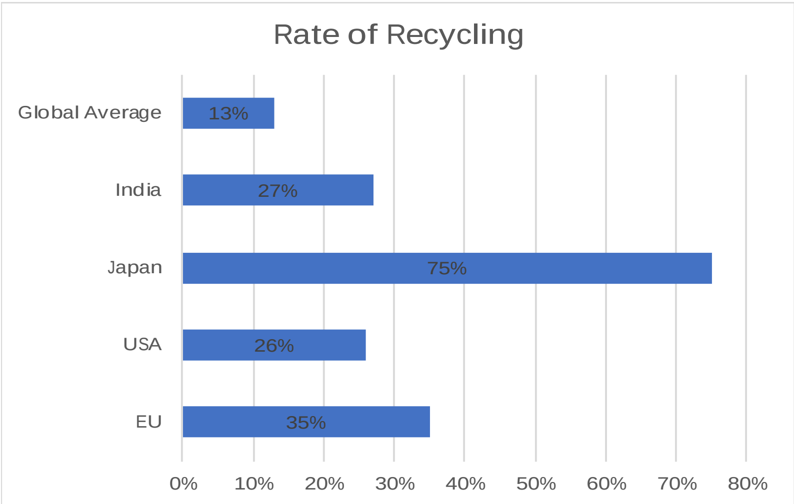

Fig. 8: Rate of E-waste Recycling in Selected Countries

Table 1: Some Valuable Metals in WEEE and Their Values

Electronic	Copper	Silver	Gold	Palladium
TV Board	50%	7%	22%	7%
PC Board	18%	5%	61%	15%
Mobile Phone	9%	13%	64%	14%
DVD-player	42%	5%	32%	5%
Value/g	£0.005	£0.42	£31.58	£22.91

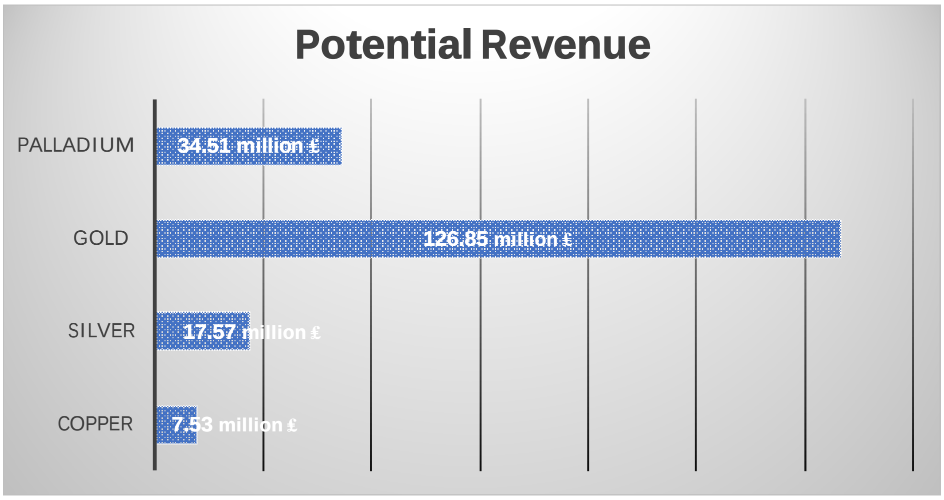

Fig. 9: Rate of E-waste Recycling in Selected Countries

As at 2014, there were 167,371,945 mobile phones in Nigeria which would transform to e-waste in a matter of 2 years. This translates to a total potential revenue of 186 million pounds or 89 billion naira with gold accounting for 68% of the total potential revenue. This amount is equivalent to 4886550 barrels of crude oil. The net revenue is however expected to be less than this estimate because recycling will require some industrial processes with their associated costs. Despite the large potentials sequestered in e-waste, they are still indiscriminately disposed and subsequently burned.

Table 2: Chemical composition

Item	Cost per Kilogramme (₦)		
	Nkpor Market, Abakpa	New Artisan Market	ESWAMA Dump/Landfill
Iron	50	60	50
Aluminium	300	300	200
Brass	500	800	800
Copper	1200	1000	1200
Brewery cans	100	100	100
Plastics	50	60	50
Bear and soft drink bottles	20	20	20
Dry gin bottles	30	20	30
Condemned battery	1500	1500	1300
Carton	20	20	20
Rubber slippers		30	
Condemned carpet		2000-8000 a spread	
Brake liner		150	
Sacks			100

4. CONCLUSION

- E-waste poses a serious environmental challenge in Nigeria
- This problem is complicated by heavy reliance and consequent importation of used EEE
- E-waste has the potential to cause environmental pollution as a result of numerous hazardous constituents
- E-waste also holds a great potential for revenue generation via recycling of constituent precious metals.

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