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Frontiers and Prospects for Recycling Waste Electrical and Electronic Equipment (WEEE) in Nigeria

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ABSTRACT: This paper reviews the frontlines and projections for the recycling of waste electrical and electronic equipment (WEEE) in Nigeria. The paper identified the sources of WEEE, showed chemical characterization of some WEEE components and presented measures to minimize these wastes through recycling opportunities. It highlighted the perspective of WEEE trails and key reasons attributed to its generation. The potentials for innovation in WEEE recycling were further discussed in line with elements of sustainability and policy directions were proffered.

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Health and environmental issues resulting from indiscriminate dumping of hazardous waste electrical and electronic equipment (WEEE or e-waste) are universally acknowledged problems. This is a fallout from the unrestrained trafficking of such wastes from industrialized nations to developing ones in Africa, South America and Asia (Okorhi, Omotor, Aderemi and Abang, 2017). E-waste are noted to be a close avenue for harmful wastes penetrating into the environment and affecting human health. As a consequence, starting in the late 1980s there arose, in many developed countries, strong stand on waste management issues with the application of stringent environmental guidelines, leading to an unprecedented rise in the cost implication of disposing harmful wastes, and frantic efforts by "toxic traders" to move hazardous wastes into developing countries which had relaxed environmental laws (GFMECD, 1995; Alo, 2009). In the search for a cut-price and faster ways to get rid of the mounting problem these illicit traders started shipping hazardous wastes to developing nations with less stringent laws on harmful wastes (Osibanjo and Nnorom, 2007, 2008; Ayodeji, 2011; The Guardian, 2012; Vanguard, 2013). However, with subsequent awareness creation, developing countries started keying into international treaties addressing harms and challenges presented by perilous wastes (Bamako 1991; StEP, 2011; NESREA, 2011b; Basel Convention, 2011a). A worldwide indignation following these actions gave rise to the formulation and approval of policies and guidelines at a convention in Basel, Switzerland - popularly referred to as the "Basel Convention" - (European Union, 2006; Basel Convention, 2011b). Hereafter, many governments started working assiduously to develop policies, guidelines and legislations to cater for managing e-waste (NESREA, 2011a, NESREA, 2011b; StEP, 2011). The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal of 1989, is acknowledged to be one of the most significant existing and inclusive global treaty addressing the WEEE problem. It's a common observation in Nigeria to find the management strategies employed to special (hazardous) waste like WEEE as the same with general solid waste management practices in the collection, intermediate storage, transporting and final disposal (Okorhi *et al.*, 2017). The use of obsolete operational legislations such the Public Health Law (Cap 134) of 1957 on Sanitation and Housing still remain part of the policy framework

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consulted by sanitation managers at the grassroots in the disposal of solid wastes (including e-waste) (Okorhi, 2015). Therefore, the recycling of e-waste is a key strategy for reducing "stockpiled" waste streams, minimizing the consumption of natural resources as well as improving energy usage.

There arose global concerns and push for answers to the rising volume of wastes from electrical and electronic equipment (EEE), the transboundary trafficking from developed to developing nations, as well as its relative negative impacts on human health and the environment (Europe Union, 2006; BCCC-Nigeria and Empa, 2011). It is reported that in 2008, nearly 180 million tonnes of End-of-Life (E.o.L) EEE were intended for landfilling in Australia. And by the year ending 2009, the country's authority established a National Waste Policy stipulating a ten year idea for material recovery and waste handling and control with a deliberate producer-led (and government support) initiative for reprocessing obsolete home appliances and computer wares (Davis and Herat, 2008; TEC, 2008; Garrett, 2009). Ongodo and William (2011) had suggested that there are four globally acclaimed issues which makes e-waste an important waste stream, vis-a-vis: global quantities of e-waste; the resource effects; impending health and environmental effects; as well as ethical concerns. Although there appear to be insufficient statistics, but estimations put the annually globally volume of generated e-waste to be between 20-50 million tonnes (Ketai et al., 2008; Basel Convention, 2011a; Ongodo and William, 2011). Secondly, the ease to getting vital production materials used in the manufacture of EEE is progressively attracting concern as the global reserves is fast decline and becoming more expensive. Another is that WEEE has over one thousand diverse constituents. Many of these constitutes are highly toxicants. They have hypothetically gravely environmental and health effects when carelessly thrown away (Agency for Toxic Substances and Disease Registry, ATSDR, 2017). Lastly, the use of juvenile for work in the informal WEEE sector in many countries of Africa and Middle East, as well as the criminal trafficking of e-waste from developed to developing nations which required frontier facilities to collect, handle, process and dispose of such category of wastes is of great concern to many (Osibanjo and Nnorom, 2008; Alo, 2009; BCCC-Nigeria and Empa, 2011; Ongodo and William, 2011; Vanguard, 2013). There has been substantial media reports on transboundary movement of WEEE in Nigeria (Puckett, Byster, Westervelt, Gutierrez, Davis, Hussain, and Dutta, 2003). These reports projected that about five hundred containers of used electrical and electronic equipment (UEEE) are been imported on a daily basis into the Ports of Lagos, Nigeria (Oresanya, 2011; Okorhi, Amadi-Echendu, Aderemi and Otejere*,* 2015a). It was also noted that in an inspection of 176 containers loaded with UEEE for categories 2-4 conducted within the months of March and July, 2010, 60% of the consignments came in from the UK alone, over 75% of the entire containers came from seaports in Europe, about 15% from countries of Asia, while 5% mainly from the seaport of Morocco and another 5% from Canada and United State of America (Ayodeji, 2011; BCCC-Nigeria and Empa, 2011). Today, many African nations are still held back with respect to legislating appropriate regulations to manage e-waste. For instance in Nigeria, WEEE is commonly managed via the municipal waste management schemes (Enugu State Waste Management Authority (ESWAMA), 2004; Okorhi et al., 2012; Okorhi, 2017). However, when the need arises, enforcement agencies often cites the stipulations of the Harmful Waste (Special Criminal Provisions) Act Cap H1 LFN 2004 for the management of WEEE and other related dangerous wastes. The National Environmental Standards and Regulations Enforcement Agency (NESREA), mandated to enforce all environmental legislations together with the checking and regulating e-waste trafficking, of late returned a WEEE carrying ship back to the United Kingdom (NESREA, 2007; Vanguard, 2013). This vessel was loaded with harmful consignments labelled as UEEE or near E.o.L EEE purported for the Nigeria environment. Before the year 2011, the same government agency had intercepted and detained 5 foreign ocean carriers loaded with WEEE designated for Nigeria (Okorhi *et al.,* 2015a). The aim of this paper is to review frontlines and projections for the recycling of waste electrical and electronic equipment (WEEE) in Nigeria.

MATERIALS AND METHODS

The key methodical concept adopted for this study is based on reviews from published literature on harmful wastes from EEE, characteristics of chemical composition of WEEE, and the types and effects of pollution from WEEE on components of the environment. The paper elicited data from secondary sources including textbooks, journals, conference articles, newspapers, policy frameworks, guidelines, by-laws and regulations. It then discussed frontiers for WEEE reprocessing and the sustainability benchmarks for evaluating and adopting technologies for e-waste recycling, some innovative e-waste recycling technologies that could be adopted by recycling firms and manufacturers, as well as the market potential for e-waste recycling at firm level.

RESULTS AND DISCUSSION

Electrical and Electronic Equipment are recognized to contain more than one thousand diverse materials, many of which are classified to be of extreme hazards (Ongondo and Williams, 2011). These items can be classified into individual components and their basic constitutes. Table 1 shows such representation. Besides, the table gave a simplified breakdown of the frequently found toxic substances in e-waste.

Table 1: Representation of some WEEE Components and Basic Constitutes

COMPONENTS	KEY CONSTITUENTS
Printed circuit boards	Lead and chromium
Cathode ray tubes (CRTs)	Lead oxide and Cadmium
Switches and flat screen monitors	Mercury
Computer batteries	Cadmium
Capacitors and transformers	Poly Chlorinated, Bi-phenyls (PCB)
EEE Plastic Casing	Brominated Flame, Retardants in casings and cables –PBBs, PBDEs
Electric cable insulation/coating	Poly Vinyl Chloride (PVC); Dioxin emissions from burning to liberate copper
Radio, amplifier and Stereo ICs	Lead and chromium; Brominated Flame Retardants in casings and cables
Batteries	Cadmium, lead
Capacitors and transformers	Poly Chlorinated, Bi-phenyls (PCB)

A Range of Frequently Found Toxic Substances in WEEE

Substance	Occurrence in e-waste
Halogenated compounds:	
- PCB (polychlorinated biphenyls)	Condensers, Transformers
- TBBA (tetrabromo-bisphenol-A) - PBB (polybrominated biphenyls) - PBDE (polybrominated diphenyl ethers)	Fire retardants for plastics (thermoplastic components, cable insulation) TBBA is presently the most widely used flame retardant in printed wiring boards and casings.
- Chlorofluorocarbon (CFC)	Cooling unit, Insulation foam. Examples founded in air-conditioners, refrigerators etc.
- PVC (polyvinyl chloride)	Cable insulation – Armored cables and other insulated cables
Heavy metals and other metals:	
- Arsenic	Small quantities in the form of gallium arsenide within light emitting diodes
- Barium	Getters in CRT
- Beryllium	Power supply boxes which contain silicon controlled rectifiers and x-ray lenses
- Cadmium	Rechargeable NiCd-batteries, fluorescent layer (CRT screens), printer inks and toners, photocopying-machines (printer drums)
- Chromium VI	Data tapes, floppy-disks
- Lead	CRT screens, batteries, printed wiring boards
- Lithium	Li-batteries
- Mercury	Fluorescent lamps that provide backlighting in LCDs, in some alkaline batteries and mercury wetted switches
- Nickel	Rechargeable NiCd-batteries or NiMH-batteries, electron gun in CRT
- Rare Earth elements (Yttrium, Europium)	Fluorescent layer (CRT-screen)
- Selenium	Older photocopying-machines (photo drums)
- Zinc sulphide	Interior of CRT screens, mixed with rare earth metals
Others:	
- Toner Dust	Toner cartridges for laser printers / copiers
Radio-active substances	
- Americium	Medical equipment, fire detectors, active sensing element in smoke detectors

Adapted from Okorhi (2015)

At the global stage, there is a legislation restricting the usage of harmful materials in the manufacturing of EEE. This is commonly cited as the "Restriction of Hazardous Substances Directive (RoHS Directive)" (European Union, 2006; Onyejekwe, 2009). The European Union approved it by legislation in the year 2003 but its full implementation commenced in 2006. In particular, this directive restricted the application of 6 substances considered to be hazardous in the manufacturing of e-devices (European Union, 2006; NESREA, 2009; Basel Convention, 2011b). These are substances of heavy metals like and complex compounds. In furtherance to this, examples and the chemical characterization for some of these substances is discussed in Table 2.

Health and environmental problems linked with e-wastes are reflected on air, land and water (Okorhi, Amadi-Echendu and Aderemi, 2015b). The impacts on air commonly arises from the burning of WEEE and expelling of gaseous components thereby introducing associated contaminants/pollutants as well as effecting the quality of air in the ecosystem. On land, the impacts of persistent organic pollutants reflect in the coarseness and colouration of soil and the worthiness of land for farming purposes. While such contaminants in water appears as introduced solid sediments, with heavy metals trace altering water taste and the standards of acidity or alkalinity of water which is inappropriate for direct consumption by humans, animal and plants. Tables 3, 4 and 5 gives detailed representation of e-waste constituents and their relative associated effects.

Table 2: Chemical Characterization of WEEE Components (Adapted from EMPA, 2009)

WEEE Constitutes	Features
Arsenic	Arsenic is a poisonous metallic element which is present in dust and soluble substances. Chronic exposure to arsenic can lead to various diseases of the skin and decrease nerve conduction velocity. Chronic exposure to arsenic can also cause lung cancer which could be fatal.
Barium	Barium is a metallic element that is used in sparkplugs, fluorescent lamps and "getters" in vacuum tubes. Being highly unstable in the pure form, it forms poisonous oxides when in contact with air. Short-term exposure to barium could lead to brain swelling, muscle weakness, damage to the heart, liver and spleen. Animal studies reveal increased blood pressure and changes in the heart from ingesting barium over a long period of time. The long-term effects of chronic barium exposure to human beings are still not known due to lack of data on the effects.
Beryllium	Beryllium has recently been classified as a human carcinogen because exposure to it can cause lung cancer. The primary health concern is inhalation of beryllium dust, fume or mist. Workers who are constantly exposed to beryllium, even in small amounts, and who become sensitised to it can develop what is known as Chronic Beryllium Disease (beryllicosis), a disease which primarily affects the lungs. Exposure to beryllium also causes a form of skin disease that is characterised by poor wound healing and wart-like bumps. Studies have shown that people can still develop beryllium diseases even many years following the last exposure.
Brominated Flame Retardants (BFRs)	The three main types of BFRS used in electronic and electrical appliances are Polybrominated biphenyl (PBB), Polybrominated diphenyl ether (PBDE) and Tetrabromobisphenol - A (TBBPA). Flame retardants make materials, especially plastics and textiles, more flame resistant. They have been found in indoor dust and air through migration and evaporation from plastics. Combustion of halogenated case material and printed wiring boards at lower temperatures releases toxic emissions including dioxins which can lead to severe hormonal disorders. Major electrical and electronics manufacturers have begun to phase out brominated flame retardants because of their toxicity.
Cadmium	Cadmium components may have serious impacts on the kidneys. Cadmium is adsorbed through respiration but is also taken up with food. Due to the long half-life in the body, cadmium can easily be accumulated in amounts that cause symptoms of poisoning. Cadmium shows a danger of cumulative effects in the environment due to its acute and chronic toxicity. Acute exposure to cadmium fumes causes flu-like symptoms of weakness, fever, headache, chills, sweating and muscular pain. The primary health risks of long term exposure are lung cancer and kidney damage. Cadmium also is believed to cause pulmonary emphysema and bone disease (osteomalacia and osteoporosis).
CFCs (Chlorofluorocarbons)	Chlorofluorocarbons are compounds composed of carbon, fluorine, chlorine, and sometimes hydrogen. Used mainly in cooling units and insulation foam, they have been phased out because when released into the atmosphere, they accumulate in the stratosphere and have a deleterious effect on the ozone layer. This results in increased incidence of skin cancer in humans and in genetic damage in many organisms.
Chromium	Chromium and its oxides are widely used because of their high conductivity and anti-corrosive properties. While some forms of chromium are non-toxic, Chromium (VI) is easily absorbed in the human body and can produce various toxic effects within cells. Most chromium (VI) compounds are irritating to eyes, skin and mucous membranes. Chronic exposure to chromium (VI) compounds can cause permanent eye injury, unless properly treated. Chromium VI may also cause DNA damage.
Dioxins	Dioxins and furans are a family of chemicals comprising 75 different types of dioxin compounds and 135 related compounds known as furans. Dioxins is taken to mean the family of compounds comprising polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). Dioxins have never been intentionally manufactured, but form as unwanted by-products in the manufacture of substances like some pesticides as well as during combustion. Dioxins are known to be highly toxic to animals and humans because they bio-accumulate in the body and can lead to malformations of the foetus, decreased reproduction and growth rates and cause impairment of the immune system among other things. The best-known and most toxic dioxin is 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD).
Lead	Lead is the fifth most widely used metal after iron, aluminium, copper and zinc. It is commonly used in the electrical and electronics industry in solder, lead-acid batteries, electronic components, cable sheathing, in the glass of CRTs etc. Short-term exposure to high levels of lead can cause vomiting, diarrhea, convulsions, coma or even death. Other symptoms are appetite loss, abdominal pain, constipation, fatigue, sleeplessness, irritability and headache. Continued excessive exposure, as in an industrial setting, can affect the kidneys. It is particularly dangerous for young children because it can damage nervous connections and cause blood and brain disorders.
Mercury	Mercury is one of the most toxic yet widely used metals in the production of electrical and electronic applications. It is a toxic heavy metal that bioaccumulates causing brain and liver damage if ingested or inhaled. In electronics and electrical appliances, mercury is highly concentrated in batteries, some switches and thermostats, and fluorescent lamps.
Polychlorinated biphenyls (PCBs)	Polychlorinated biphenyls (PCBs) are a class of organic compounds use in a variety of applications, including dielectric fluids for capacitors and transformers, heat transfer fluids and as additives in adhesives and plastics. PCBs have been shown to cause cancer in animals. PCBs have also been shown to cause a number of serious non-cancer health effects in animals, including effects on the immune system, reproductive system, nervous system, endocrine system and other health effects. PCBs are persistent contaminants in the environment. Due to the high lipid solubility and slow metabolism rate of these chemicals, PCBs accumulate in the fat-rich tissues of almost all organisms (bioaccumulation). The use of PCBs is prohibited in Organization for Economic Cooperation and Development (OECD) countries, however, due to its wide use in the past, it still can be found in waste electrical

	and electronic equipment as well as in some other wastes.
Polyvinyl chloride (PVC)	Polyvinyl chloride (PVC) is the most widely-used plastic, used in everyday electrical and electronics appliances, household items, pipes, upholstrery etc. PVC is hazardous because contains up to 56 percent chlorine which when burned produces large quantities of hydrogen chloride gas, which combines with water to form hydrochloric acid and is dangerous because when inhaled, leads to respiratory problems.
Selenium	Exposure to high concentrations of selenium compounds cause selenosis. The major signs of selenosis are hair loss, nail brittleness, and neurological abnormalities (such as numbness and other odd sensations in the extremities).

Table 3: WEEE Components and Associated Effects on Human Health and the Environment NESREA (2009)

		ENVIRONMENT	HEALTH
1	Lead (Pb)	• Accumulates in the environment • Potential to leach and contaminate drinking water supplies.	• Exposure to lead, even at very low levels, is highly toxic • damage to the central and peripheral nervous systems • lead exposures can significantly reduce the IQ of school-aged children • In adults, lead exposure has been related to increased blood pressure and hypertension, conditions known to increase the risk of cardiovascular disease. • Affects blood system and kidneys in humans • Exposures can cause infertility and miscarriage • endocrine hormone disruption • Lead inhibits the various enzymes of the haemoglobin metabolism thus reducing the oxygen balance and the respiratory volume
2	Cadmium (Cd)	• Danger of cumulative effects in the environment due to its acute and chronic toxicity.	• Irreversible effects on human health. • Accumulates in the human body, in particular in the kidneys. • Biological half-life of cadmium in the human body is between 15 and 25 years (measured in the kidneys) • Cadmium and its compounds are carcinogenic • Bone deformation may also result
3	Mercury (Hg)	• Accumulates in living organisms and concentrate through the food chain, particularly in fish.	• Negative effects on brain functioning and development • Mercury dusts and vapours are very toxic. It is subject to almost complete absorption via the lungs. • Mercury is finally stored in the liver and kidneys and • Chronic poisoning causes malfunction of the central nervous system, the symptoms being apathy, unretentive memory, over-excitability and general trembling. • It has mutagenic and teratogenic potential
4	Hexavalent Chromium		• Can cause strong allergic reactions, even in small concentrations. • Acute poisoning with chromium (VI) compounds becomes apparent in the form of damage to the kidneys. • Chronic poisoning results in changes in the gastro-intestinal tract as well as in accumulation in the liver, kidneys, thyroid gland and bone marrow • Chromium(VI) compounds are highly mutagenic
5	PVC(Poly vinyl Chloride Plastics)	• The production and burning of PVC products generates dioxins and furans, which contribute to air pollution	• Is an important irritant and allergen of eyes, skin and respiratory tract • Aggravates respiratory ailments. • Repeated exposure damages the liver, kidneys and spleen • Malignant tumours may occur. • definitely carcinogenic and teratogenic (deformities and skeletal changes on inhalation)
6	Brominated Flame Retardants	•	• Exposure to these chemicals in early life could induce neurotoxic effects • Exposure to Polybrominated Biphenyls (PBBs) is believed to cause an increased risk of cancer of the digestive and lymph systems. • The liquid produces severe, poorly healing irritation and burning of the eyes, the respiratory organs, the skin and the gastro-intestinal tract. • Deep, painful necroses form on the skin and the mucous membranes. • High concentrations cause oedemas of the glottis, larynx and lungs as well as inflammation of the lungs. • Bromine vapours are even more hazardous as they produce bronchial spasms and pneumonia.

Complete industrialization of Africa could be achieved by sustainable innovation and awareness creation of its innovative potentials. Until lately, policy frameworks for e-waste management are simply focused on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, as well as Extended Producer Responsibility programmes for E.o.L EEE (Okorhi, 2015).

Table 4: Tabular Representation of the WEEE Components and Associated Impacts on Air, Water and Land NESREA (2009)

S/N	Component	Environment		
		Air	Water	Land
1	Lead (Pb)	Lead compounds may be transported over a considerable distance depending on the speed and direction of the wind as well as precipitation and humidity. However, most of the lead in the atmosphere directly sediments or is removed by precipitation. Lead bonds to small dust particles in the air which in turn are deposited on vegetation and soil	• Surface water forms an accumulation sink for lead compounds. • Insoluble lead compounds sink and are adsorbed in the sediment or accumulate on suspended matter (in particular the clay fraction). • Aquatic plants likewise accumulate lead. • The biochemical oxidation of organic substances is inhibited at lead concentrations above 0.1 mg/l • fauna is depleted by concentrations above 0.2 mg/l • Groundwater is adversely affected by soluble lead compounds (e.g. lead chloride, nitrate)	• The absorption rate depends on the properties of the soil. There is a considerable affinity with humic substances. The pH of the soil is important for the availability of lead from its compounds. • Lead is quite immobile (e.g. more than cadmium), it remains in the topsoil and is not absorbed by plants to the same extent. • Soils thus represent an important sink for lead compounds
2	Cadmium (Cd)	Cadmium is stable in air since it forms an oxide layer.	• 2/3 - 3/4 of the cadmium in surface water and groundwater is adsorbed on suspended matter. • It can be remobilised from sediment by complexing agents. • Fish toxicity is dependent amongst other things on the calcium content of the water	
3	Mercury (Hg)	Washed out more or less completely by precipitations.	• inhibits the metabolic activity of microorganisms in water • Suppresses the self-purification capability of water at concentrations as low as 18 m g/l. • Adsorbed on sediment and suspended matter.	
4	Hexavalent Chromium		• The toxicity of soluble chromium compounds in aquatic systems varies depending on the temperature, pH and water hardness as well as on the species of the organism. Chromium(VI) compounds are readily • soluble in water, but are readily reduced under natural conditions in the presence of organic, oxidisable material to form less water-soluble, stable chromium(III) compounds.	
5	PVC(Polyvinyl Chloride Plastics)	On expansion, the pressurized gas forms cold mists which are denser than air. Evaporates easily and form toxic, explosive mixtures.	• Persistent in water, if not evaporating. • there are no known cases of damage to aquatic organisms • Accumulation in the aquatic food chain is unlikely	
6	Brominated Flame Retardants	The liquid readily evaporates and forms caustic vapours.	• Bromine is denser than water, but dissolves slightly in water and colours it brown. • There is a strong hazard to all types of water, in particular to drinking water, service water and waste water on account of the high toxicity linked to oxidising and corrosive properties	

An innovative trend on sustainability in WEEE management has incorporated the application of frontiers like organic field effect transistors (OFETs) Technology, Organic thin-film transistors (OTFTs), organic light emitting diodes (OLEDs), and organic photovoltaics (OPVs) in the manufacturing of EEE (Okorhi *et al.*, 2015b). Therefore paving ways for technologies of biodegradable materials as suitable products to hitherto inorganic components in EEE manufacturing. According to a report published by Schluep, Hagelueken, Kuehr, Magalini, Maurer, Meskers, Mueller, and Wang (2009), sustainable innovation refers to the shift of sustainable technologies, products and services to the marketplace, requiring a market creation concept and a shared global agenda. Whereas, environmental management and sustainability focuses on findings solutions to global pressing environmental problems.

It is said that the best available environmentally sound management (ESM) systems are programmes and techniques that produces sustainable environment through its protection, paving way for safer health and working conditions, generating employment as well as other socio-economic benefits (Okorhi, 2015). In pursuit of these, there arises the deployment of frontier strategies (including the 5Rs) for e-waste management. However, the activities of metal recyclers in Nigeria are only indirectly linked to the e-waste recycling sector, as the business outputs are functioning products rather than raw materials (Basel Convention, 2011a).

Table 5: Empirical Data to support Table 3 and 4

S/N	COMPONENT	DATA
1	Lead (Pb)	In Germany, lead is listed in pregnancy group B (risk of embryonic damage is assumed). Symptoms of chronic poisoning are lead deposits along the edge of the gums as well as colic fits and spasms. Apathy, irritability, insomnia and - in some cases - behavioural irregularities in children are indications of damage to the nervous system. Lead passes through the placenta and accumulates in the foetus. In Germany, lead is listed in pregnancy group B (risk of embryonic damage is assumed).
2	Cadmium (Cd)	In Asia, "Itai-Itai" disease is caused by high cadmium concentrations in rice. Twelve patients with Itai-Itai disease, thought to be caused by chronic cadmium poisoning (Ishizaki, A: Asian Med. J. 14:421-436, 1971), showed chromatid aberrations.
3	Mercury (Hg)	Responsible for the Minamata Bay Disease of Japan in 1962. Released Mercury chloride bioaccumulated in shellfish and fish in Minamata Bay and the Shiranui Sea, which, when eaten by the local populace, resulted in mercury poisoning. While cat, dog, pig, and human deaths continued for 36 years, the government and company did little to prevent the pollution. The animal effects were severe enough in cats that they came to be called "dancing cat fever".
4	Hexavalent Chromium	The carcinogenic effect of chromium (VI) compounds has been substantiated both in animal experiments and by epidemiological studies on groups of population subject to workplace exposure. The corresponding latency times are given as between 10 and 27 years.
5	PVC(Polyvinyl Chloride Plastics)	The US Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.
6	Brominated Flame Retardants	Due to the Michigan accident in 1973-1974, many toxicity studies on PBBs are available. Soil samples from a former PBB manufacturing site, analysed several years after the Michigan incident, still contained PBBs though the PBB congener composition was different, indicating a partial degradation of the PBB residues in the soil sample. Increased levels of polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) were found in breast milk samples in Accra, Ghana.

Adapted from the GFMECD (1995) Handbook and NESREA (2009)

Nevertheless, the 2011 Basel Report found the sector producing significant amount of e-waste. This is because the e-waste recycling sector in Nigeria is dominated by firms (or individuals) with "informal" arrangements which collect WEEE at random, manually dismantling (or sorting), preprocessing, selling of valuable components and, dispose of the leftovers (Okorhi, 2015). For instance, precious metals contained in printed wiring boards (PWBs) are rarely collected and when they are, are sold below world market prices to traders that organize exports to Asian recycling facilities (Basel Convention, 2011a). Also, some devices extracted from WEEE are then used as spare parts in the repairs of faulty EEE.

Obviously, the ease to getting vital production materials used in the manufacture of new EEE is gradually drawing fear as world reserves of raw materials is quickly reducing and getting more expensive (Ongodo and William, 2011). The overall aim for "formal" e-waste recycling is to avert hazardous materials from WEEE in an ESM manner; recover prized items as much as possible; build an eco-friendly and sustainable SMEs and; consider the socio-economic implications (Schluep *et al.,* 2009). For a better consideration of the procedure for selecting innovative e-waste recycling technologies in developing countries, Schluep *et al.* (2009) suggested, among others, the importance of sustainability benchmarks. Table 6 shows the sustainability benchmarks for evaluating and adopting technologies for e-waste recycling in developing countries, including Nigeria. The criteria to compare the innovation of technologies was then grouped along the elements of sustainability. Whereas Table 7 shows some innovative e-waste recycling technologies that could be adopted by e-waste recycling firms in Nigeria. To sum up, the market potential for e-waste recycling are enormous as the annual growth rate of WEEE in Nigeria is put at 10% in the volume of waste generated (Ayodeji, 2011). It has been identified that a mid-term medium potential for integrated e-waste smelting already exist in some countries of Asia, Africa, South and North America (Schluep *et al.,* 2009). Hence, from job creation, entrepreneurship and sustainability viewpoints, the “informal” practices of collection and manually dismantling of e-waste may not really require a transformation to a “formal" arrangement using high-tech equipment for the processing of WEEE (Rochat and Rodrigues, 2008). The innovative technologies been continuously adapted by the larger informal sector in Nigeria is now gaining ground (Basel Convention, 2011a). Opportunities in recycling of e-waste arises in the improvement of the processing of cable-coated from poly-vinyl-chloride and insulators, and poly-brominated biphenyls coated plastics. Also is the collection of large quantities of PWBs for export and fair pricing. By using the voluntary carbon standard (VCS) or carbon action reserve (CAR) schemes, there is now the potential of recovering chlorofluorocarbon from cooling units and insulation foam which in turn brings both environmental and economic gains (Basel Convention, 2011a). It was also suggested that the improved utilization of polystyrene from e-waste recycling would guarantee a higher monetary value from the pricing of carbon (IV) oxide.

Table 6: Sustainability Benchmarks for Evaluating and Adopting Technologies for E-Waste Recycling In Developing Countries (Schluep *et al.,* 2009)

Attributes	**Indicators involved**
Economic attributes	
Low net costs	Costs for transport, processing and labour vs. revenues
Low capital costs	Investment costs for additional plants and technologies used in a scenario
Increased potential for local economic growth	Additional industries and services involved by implementing a scenario
Environmental attributes	
Low use of electricity	Savings of electricity but also energy in general by implementing a scenario
Low fuel use for transport	Fuel used by shipping and road transport
Low use of freshwater	Freshwater consumption of a recycling scenario
Little (toxic) emissions	Caused vs. prevented emissions according to the savings of raw materials calculated with eco-indicator ’99 (or other appropriate tools)
High metal recovery rates	Range and yields of metals contained in the waste, which can be recovered and used as secondary raw material. In case of technical conflicts prioritization by economic and environmental value (“footprint”) of the recovered substances.
Social attributes	
Creation of jobs for the previously unemployed	Working hours for low-skilled and semi-skilled workers generated
Creation of highly skilled jobs	Working hours for highly skilled workers generated
Creation of jobs outside the target country	Working hours generated outside the target country
Low health and safety impacts	Impacts of a scenario on health and safety of the employees engaged in a scenario

Table 7: Innovative E-Waste Recycling Technologies for Recycling Firms (Schluep *et al.,* 2009)

	Waste streams	**Economic attributes**	**Environmental attributes**	**Social attributes**
Manual dismantling/ sorting of fractions	All	Low capital cost, sorting of valuable fractions/ components	Efficient sorting of fractions	Labour intensive, Job creation
De-gassing CFC, HCFC	C&F	Mandatory requirement having low cost	Fundamental step to ensure control over hazardous substances having huge GWP potential	
Semi-automatic CRT cut and cleaning	CRT	Low capital and net Cost	Low energy consumption	Labour intensive
Integrated smelter for non-ferrous (pyrometallurgical methods)	Non-ferrous (including printed wiring boards) like Cu, Pb, Zn, Sn or mix	Capital cost high Low net (unit) costs due to economies of scale Local growth potential High	No toxic emissions Low water use Transport: internationally Little waste products Recovery rates >> 90%	Automated process control so less jobs created Highly skilled workforce EHS*
Aluminium remelter/refiner	Aluminium	Captial cost medium – high Net cost low Economies of scale	No toxic emissions Salt slag has to be treated or disposed Env. sound Transport within region or country Water use: low - medium	Job creation: yes Mix of low skilled and high skilled jobs EHS low risks

The Bamako Convention had emphasized the need for urgent introduction and enforcement of policies at all arms of government dealing specifically with WEEE streams. This review has identified the sources of WEEE, its characterization and frontline technologies in managing the WEEE problem through recycling. Proposed recycling frontiers should be adopted in line with elements of sustainability and market potentials. Specifically, legislations should reflect more on potentials for recycling thereby promoting conservation, entrepreneurship and job creation.

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