Development of E-Waste Inventory Management Strategy: Case Study

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Abstract
This research study assessed the challenges faced in managing e-waste in the case study industrial area with a view to develop a sustainable e-waste management framework for e-waste generated by industries based in the vicinity. A questionnaire based survey was use to evaluate e-waste management methods currently implemented by industrial operators; and to establish challenges restricting e-waste management. Effort was made to characterize the e-waste generated by various operations in the area. The survey established that resulting lack of e-waste strategy was attributed to low awareness levels, and lack of procedures or technology to manage e-waste hence no proper collection and disposal of e-waste, high growth of e-waste, lack of e-waste policy and stakeholder collaboration. The study recommended the development of a framework towards a sustainable e-waste management system which entails a process of e-waste inventory management routine, proper collection and recycling schemes as well as possible strategic and synergistic approaches towards e-waste management.

Keywords
E-waste, collection, disposal, generation, recycling, inventory, management

1. Introduction
Industrialization has been greatly influenced by advancement in technology hence most industries are now incorporating electrical and electronic equipment in order to enhance production processes. However, the high obsolescence rate of these equipment and related components has seen the maintenance management crews in most industries experiencing an increasing inventory of discarded electrical and electronic equipment. According to (Gaidajis et al 2010), all components, consumables and sub-assemblies which are part of any electrical and electronic equipment when obsolete are categorized as electrical or electronic waste (e-waste). E-waste is one of the fastest growing waste streams worldwide and it constitutes of valuable metals and non-metals as well as hazardous substances such as lead and mercury that contaminate the environment (Mahajana et al 2015). In an attempt to effectively manage such form of waste, there is need for safe, scientific and environmental sound treatment methods that are governed by adequate infrastructure and policies as requirement (UNEP 2007). Integrated waste management procedures which involve reuse and recycling are adopted as the most preferred treatment methods to attain the benefits of reduced environmental health threats whilst realizing conceivable economic incentives from the electronic waste materials. Despite the possible benefits of e-waste management, Zimbabwe like most of the developing countries lacks a defined e-waste treatment strategy. At industrial level, conventional methods of solid waste management have proved failure to accommodate e-waste. Many at times when repairs or replacements are done, the unwanted electrical and electronic equipment components are just added to the increasing inventory due to lack of a proper framework to manage these obsolete items. As a result, there rises a need to urgently characterize the nature of e-waste being generated in various industry operations, evaluate the current e-waste handling methods hence design an enhanced and practical framework for the effective e-waste management implementable in the local industrial environment.

2. Justification

Rapid variations in technology, changes in devices, falling prices, and planned obsolescence have caused a fast-growing surplus of electronic waste around the globe which consists of circuitry components such as capacitors, batteries, switches which contains hazardous substances like mercury, beryllium, cadmium and lead hence require proper handling. Adding to that, e-waste also consists of retrievable valuable materials such as gold, plastic and copper which can used as secondary raw materials. Despite the above knowledge, no known policy or strategy is available at national or industrial level so as to manage e-waste. Most of the electrical and electronic products are being continuously imported and at a high rate of which no local take-back systems are there to collect the end-of-life equipment and components hence consumers including the industry lay clueless on ideas to handle the accumulating e-waste. Low level of awareness about e-waste has seen industries lack the zeal to characterize or quantify their accumulating waste and also to develop e-waste handling infrastructures. However, in a broader perspective, increase in industries and technologies is the talk of the modern day which implies more e-waste generation hence notable environmental impacts. It is for this reason that a research study was initiated to develop a framework in the local active industrial area of Graniteside in Harare as a case study. This industrial site is facing the increasing e-waste inventory hence reduced space, storage costs, and environmental pollution risks are the resulting challenges. High obsolescence rate of electrical and electronic equipment is pushing for fast deterioration hence high accumulation of the e-waste inventory. In view of the expected boom in local economy and advancement in technologies, an increase in industrial activity will result into more e-waste generation in the coming years. Therefore, industries require a proper framework to manage e-waste and identify the waste resource value whilst avoiding environmental threats.

3. E-waste over view

3.1 Definition and e-waste trends

The term e-waste refers to electrical and electronic equipment when it is unwanted or obsolete. The scope of e-waste covers a range of electrical and electronic products from domestic appliances to office and industrial equipment when disposed of. E-waste generation is increasing more than any other waste streams with the generation statistics for 2017 indicating a 33% increment of e-waste volumes from the 2014 value (Sotelo et al 2017). In developing countries, increasing generation rate of e-waste is being strongly contributed by the rapid technological growth, continuous updates of products and the reduction in life spans. Therefore, the present threat is that, most developing countries are still lagging on the understanding on e-waste and best ways to manage it. The risk of the later is that, the e-waste inventory is continuously increasing although characterized as complex as it is comprised of components of economic value mixed with various toxic substances that have adverse effects on human health and the environment.

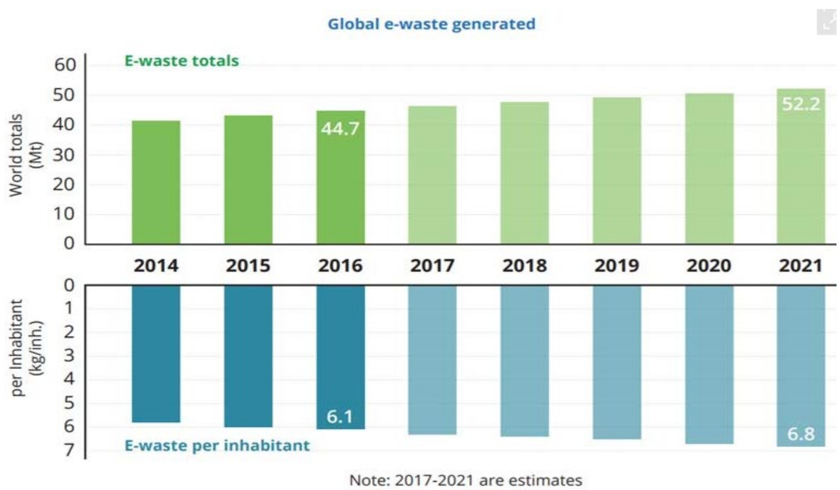

Figure 1.Rate of e-waste generation (CIA World Factbook 2018)

As earlier stated, e-waste originates from obsolete electrical and electronic equipment and, (Gaidajis et al 2010) broadens up to say components, consumables and sub-assemblies which are part of the electrical and electronic equipment at the time of discarding are considered as e-waste as well. According to (Step 2014), an electrical and electronic equipment is any item with circuitry or electric components which relies on electromagnetic fields or electric currents so as to function properly, including those equipment used during the generation, transfers as well as measurement of the current. However, the European Directive in (Barletta et al 2016) narrows up on the broad spectrum of e-waste to say e-waste results from equipment that use voltage below 1000V for AC and 1500V for DC.

3.2 E-waste generation cycle

E-waste generation traces a path of from equipment acquisition, consumption up until obsolescence. The knowledge of material flow determines the overall flow network of resources or products together with the responsible stakeholders along the equipment life cycle. Figure 2 gives a general product life cycle of electrical and electronic products.

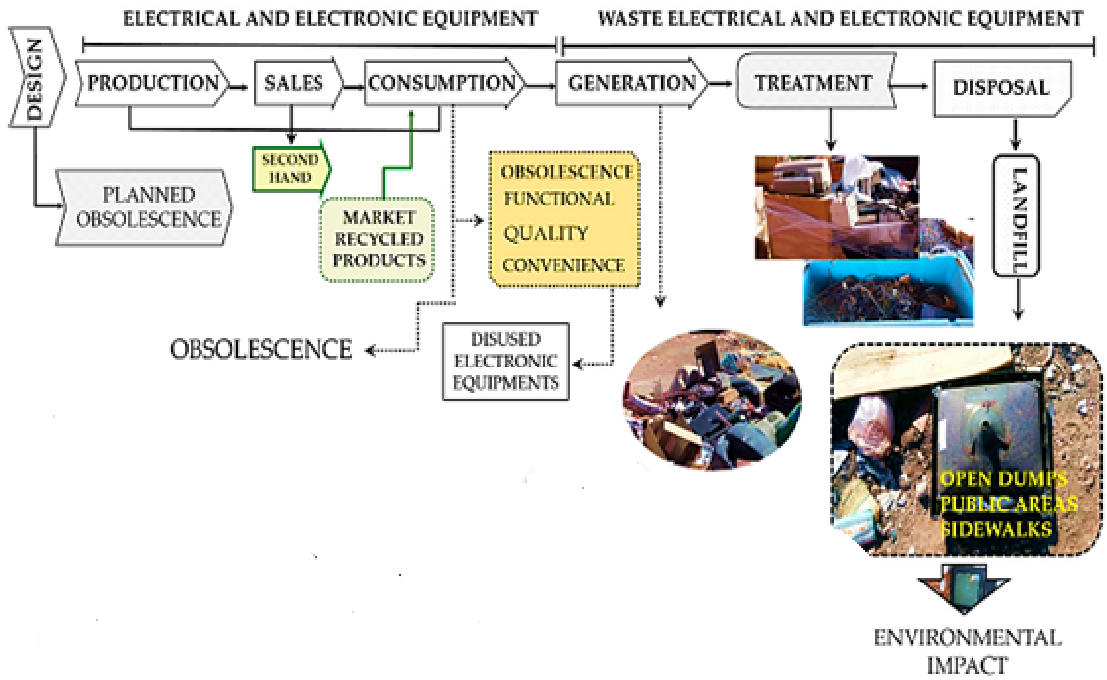

Figure 2.Electrical and Electrical Equipment product life cycle (Sotelo et al 2017)

Technological obsolescence is the main factor influencing the generation of e-waste amongst domestic and industrial consumers. The phenomenon explains state of non-compatibility of equipment towards its intended functions. Three key drivers that influence obsolescence are (Sotelo et al 2017):

Functional obsolescence: A scenario when a superior product substitutes another of inferior functionalities.

Quality: A scenario when equipment is declared obsolete due to underperformance.

Convenience: A case when an equipment although functional and with no better replacement stops being preferred because of mode or style.

Technological obsolescence can be considered the major driver of electrical and electronic equipment disposal as it stimulates the need to replace devices or equipment hence a behavior which directly impact e-waste generation. However, the upgrading of the equipment is as well related to affordability and availability of the market which are factor also related to the economic state of a region. (Gaidajis et al 2010), anticipate that increase in economy growth reflects higher e-waste generation rate due to availability and affordability of commodities within a geographical boundary. Furthermore, it is important to also note that with affordability of commodities, loopholes for counterfeits of substandard in the market advent hence resulting in the fast wear and tear of the equipment. Therefore, the downstream communities that are affected the most are the developing regions which are continuously consuming these shortened lifespan equipment so as to match other industrialized nations. To this end, it can be discussed that e-waste generation will continuously rise with the upsurge in economy growth, increase in industries and high obsolete rates due ever improving technologies. This then hints on the establishment of e-waste management systems to tackle e-waste soon after the consumption stage rather than resorting to storage of obsolescence inventories or any other poor handling methods.

3.3 Sources of e-waste

Major sectors responsible for e-waste generation include the industry, universities, business offices, households and government agencies. These sectors incorporate electrical and electronic equipment in their distinct processes hence the e-waste generated is as well distinct to each sector.

Domestic: Households are amongst the major sources of e-waste because they consume a high quantity of electrical and electronic equipment. E-waste from household cover the categories of household appliances and IT and consumer equipment. Household appliances or white goods consist of equipment such as irons, toasters and clocks, oven, refrigerators, stoves and washing machines. IT and consumer equipment or brown goods consist of equipment such as personal computers, televisions and mobile phones.

Institutions: The sectors that include businesses, institutions, and government agencies exist as e-waste sources because of their high usage and quantities of electronic equipment such as printers, computer and copiers. In these sectors continuous upgrading of equipment is always done to match with the advancing technology hence better efficiency and organizational productivity. For instance, computers are periodically upgraded for compatibility with recent software.

Industries: Industries range from in activities such as manufacturing, service and processing. They generate e-waste when electrical and electronic equipment are no longer functional or modern with respect to the changing technologies and this is mostly influenced by the need to improve quality in production. Modern industries now incorporate vast electrical and electronics in their processes for instance control systems circuits in manufacturing and process industries can comprise of inductive components like motors, capacitors, resistors, transducers and sensors. Adding to that, industries involved in service also use electrical and electronic equipment such as air-conditioners and heaters for office conditioning, computer, printers and photocopiers for data processing, and devices of importance in communication such as phones. However, it is important to note that manufacturers of electrical and electronic equipment as well generate e-waste when new products are rejected on the production line or fail to meet the quality standard during process.

Imports: Another source of e-waste is through imports. In developing countries, e-waste is usually imported from industrialized countries. The used equipment from the industrialized nations will be of attractive prices and still good enough for usage. However, the products will be of shortened lifespan hence they accumulate as e-waste at a faster rate. (Feresu 2010).

3.4 Characteristics of e-waste

Broadly e-waste is composed of plastics, plywood, PWBs, glass, concrete, rubber, ferrous and non-ferrous metals, ceramics and other contents. According to (Vats & Singh, 2014), e-waste is a complex mixture of valuable metals and non-metals as well as hazardous pollutants. Of the valuables in the waste, 47.9% is iron and steel, 21% plastics and 13% non-ferrous metals. The non-ferrous metal includes copper, aluminum and precious metals. The ratio of precious metals is estimated as Silver 0.2%, Gold 0.1% and Palladium 0.005% (EPA, 2011).

Mostly metals are incorporated in the equipment make due to their high melting points and electrical conductivities whilst plastics are good insulators, high temperature resistant, rigid, high impact strength and creep resistant.

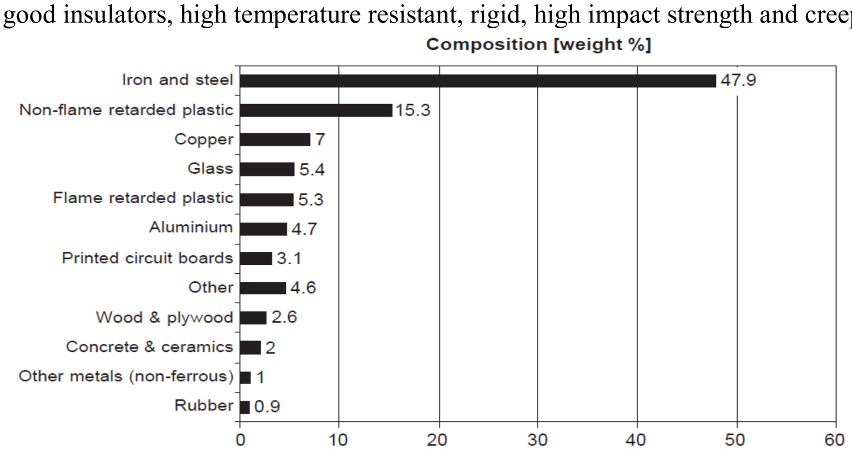

Figure 3.E-waste material composition (EPA, 2011)

On the other hand, e-waste consists of pollutants that are embedded in various materials in the equipment make. Plastics contain PBDEs which save as flame retardants and printed circuit boards comprise of chromium (Cr), cadmium (Cd), Lead (Pb), arsenic (As), mercury (Hg) and other toxic substances. According to, a usual printed circuit boards can contain 50g/m^2 of tin-lead solder (Mmereki et al., 2016). Adding to that, e-waste also consists of chlorofluorocarbons (CFCs) in obsolete refrigerators, air conditioning units and freezers. Cathode ray tubes (CRTs) in TVs and computer monitors host material such as copper, lead, cadmium and zinc. A typical CRT can contain an average of 1.6-3.2 kg lead (Chancerel 2010). However, it is of importance to note that the fraction of these pollutants is always changing with advancement in technology.

3.5 Hazardous compounds in e-waste

E-waste comprise of a multitude of hazardous substances embedded in various e-waste components. The various substances and their location in e-waste can be described follows:

Lead: Lead is commonly used in solders, as an alloy element for machining metals, incandescent light bulbs, cable covering and printed circuit boards. Its oxide is used in the cathode ray tubes leaded glass and batteries. Tin-lead lead solder signifies the chief solder type used in most equipment motherboards, 50g/m^2 lead are expected per typical motherboard(Mmereki et al 2016).

Cadmium: Cadmium is concentrated in semi-conductor chips and resistors in printed circuit boards, batteries, photocopying machines, printer inks and toners, cathode ray tubes, and infrared detectors. The element is also used in stabilizing PVC. In Nickel-Cadmium batteries, cadmium forms the negative electrode material. It is also used as an alloying element in making low melting brazing or soldering alloys. The oxide of the element occurs in nickel-cadmium batteries and its supplied compound is used in Cathode ray tubes as well as most electronic devices. Cadmium bio accumulates in body parts such as the liver, pancreas, kidney and thyroid hence posing irreversible effects on the human health.

Mercury: Mercury is found in relay and switches, mobile phones, batteries and relay sensors, gas discharge lamps, ovens, leveling devices, thermostats, air-handling units, pumps and electric ranges. However, exposure to mercury causes brain and kidney damage, affects the cardiovascular system, affects developing fetus, trigger depression and suicide. Furthermore, inorganic mercury mixes with water to form methylated mercury which bio-accumulates in incarnate organisms, mostly fish hence affecting the food chain (Mahajana et al 2015).

Chromium: Hexa-valent chromium is a chemical component is used for decoration and hardening steel housings as well for combating corrosion in untreated and galvanized steel plates. The use of this compound in usually in trace amounts. However, the chromium affects the skin sensitivity and compromise the DNA strand due to the fact that it can easily pass through cell membranes hence highly absorbed in cells leading to their contamination (Mahajana, , et al., 2015).

Beryllium: Beryllium is mostly found in finger clips, power supply boxes and motherboards where it is used to strengthen connections. It has high electrical and thermal conductivity, good fatigue resistance, good corrosion resistance and good formability. It used to improve the properties of copper such that 2-4% of copper alloys is beryllium metal. However, Beryllium exposure can cause lung cancer and skin diseases years after (Mahajana et al 2015).

Brominated flame retardants: Brominated flame retardants (BFRs) are used in equipment plastic casing and circuit boards to avoid flammability. They are used occur in components like connectors and cables .The BFRs are used as reactive or additive flame retardant in many polymers like epoxy and phenolic resins, high impact polystyrene and adhesives. However, BFRs are suspected to be toxic due to their tendency of polluting the atmosphere and also undergoing bio accumulation (Mahajana et al 2015).

PVC: Polyvinylchloride (PVC) is ubiquitous in electronic equipment as it is used in cables, keyboard and computer housing. PVC has excellent chemical resistance and is mostly chosen for its durability quality. However, burning of these at low temperature yields dioxins to the environment(Mahajana et al 2015).

***PCB**:* The make-up of a capacitor has a pair of conductors that are separated by a dielectric, which in older capacitors the dielectric is made up of PCB-oil (polychlorinated biphenyls).The PCBs are of adverse impact on humans and environment.

3.6 E-waste contamination on the environment

E-waste affects the environment through soil, air, water and humans. The e-waste contaminates disturb the environment in case of inappropriate handling methods. (Gupta 2012), describes 3 levels of emission of e-waste toxins into the environment as (i) Primary emission: This involves the release of hazardous substances contained in e-waste such as lead, arsenic, mercury, PCBs and cadmium,(ii) Secondary emission: This involves the release of products of reaction due to improper treatment such as furans or dioxins formed due to incineration of plastics with

halogenated flame retardants (iii) Tertiary: This involves the release of hazardous substances or reagents used in e-waste treatment such as cyanide or other leaching agents. Therefore, the environmental risk of such hazardous pollutants can be as a result of the nature of waste and how it is being collected, processed, recycled or disposed.
Water and aquatic: E-waste pollutants can pass into aquatic systems through leaching from dumpsites where treated or untreated e-waste may have been deposited. Heavy metal like lead and mercury as well as PBDEs and PCBs can leach into ground water in case of disturbance of the components hosting such pollutants (Gupta 2012). Likewise, the discarding of acid after hydro metallurgical procedures into waters or onto soils, as well as the dissolution or settling of airborne contaminants, can also result in the contamination of aquatic systems.
Air: Many E-waste pollutants are spread into the air through dust. This is a major exposure pathway for humans through ingestion, inhalation and skin absorption. Combustion or low temperature melting of e-waste can cause the release and fast travel of flame retardants such as PBDEs, furans and dioxins which pollute the atmosphere(Chitotombe 2013).Adding to that, substances such as lead, copper, tin, Cadmium and Zinc are possible pollutants that can be emitted from e-waste(Robinson, 2009).
Soil and terrestrial environment: Soils from the site of crude e-waste handling are at risk of contamination by primary emission of heavy metals such as lead and mercury as observed in dumpsites. Tertiary emissions of acid reagents used in e-waste treatment result in soil leaching. These leachates bio- accumulates in soils and affect farm produces and the rate of plant growth. PBDEs, PAHs, Cadmium, Lead and mercury are some of the pollutants according to (Robinson 2009).

Human: The contamination of soil, water and air subsequently threatens human health. Possibilities are that, humans might ingest water from contaminated sources or food from contaminated soils hence susceptible to various diseases as previously discussed under 2.5.Adding the above, contaminated air inhalation can affect humans in the later stages of life. According to, exposure to e-waste contaminates can affect humans in various ways such as high levels of pollutants in human milk, hair, placentas and the blood system which might cause DNA damage(Robinson 2009).

3.7 E-waste management options

According to (Sawhney et al 2008), e-waste management is a systematic way of controlling and monitoring electronic products when unwanted and discarded. The best treatment methods have to yield reduced environmental health threats whilst with the ability to recognize the waste resource value (Dwivedy and Mittal 2012, Mmereki et al 2015). However, (Rose et al 1999, Tanskanen 2012) argued to say e-waste collection is an important aspect prior to anything else because the efficiency of the chosen treatment methods will depend on the volume and quality of the e-waste collected. Therefore, rounding up these philosophies, the components of e-waste management can simply be viewed as a combination of proper collection and environmental sound treatment strategies that yield economic opportunities. Policies aid in the maximum control of the waste along its lifecycle and creating shared responsibility between affected stakeholders hence accountable for the effective collection and treatment of the waste supply. Such helps in the public to participate in the waste management decision making processes thus yielding a sustainable system which allows for continual improvement basing on the triple bottom line performances of sustainability i.e. economic, environment and social(Joseph 2006, Garnett and Cooper 2014).

Policy: Policies and legislations are essential to govern the waste management system such that it becomes a long term goal by stimulating awareness and shared responsibility between relevant stakeholders involved in the e-waste management system such that there is demarcation of different roles and responsibilities between them. These roles involve actions implemented towards effective, mature collection and treatment system for electronic waste.
Extended Producer Responsibility (ERP): EPR is an environmental policy set towards improved collection and treatment of end of life products. The producer is forced not to limit his financial and physical responsibilities to environmental impacts created during production process but rather extend the responsibilities across the product's lifecycle, thus from production up until post-consumer stage when the product is taken back for recycling and proper disposal (Manomaivibool 2009, Mmereki et al 2015). Consumers' contribution is mostly through internalized environmental cost in the product price to boost the treatment process.
Collection: Collection is a crucial step in an e-waste management system involving the process of recovering discarded products. Appropriate collection involves segregation of the e-waste from other regular wastes in order to administer special treatment methods. Motivation of e-waste collection ranges from environmental protection as the waste is diverted from improper disposal to economic inducements as the resultant waste treatment supports resource recovery.(Chancerel 2010, Hai-Yong and Schoenung 2005, Jofre and Morioka 2005), classified collection methods into the following various models, (i) Drop-Off Programs: This is an organized one day collection through

existing municipal services.(ii)Curbside/Pick-up Collection: This is the collection done periodically at homes and offices.(iii)Distance Collection: The sender posts the e-waste to the collector.(iv)Point-of-purchase: The retailer does the collection of used products.(v)Permanent Collection: This is involves a permanently designated place used for the continuous collection and temporary storage of used products. A coordinated model can be formulated by combining the various collection approaches(Jofre and Morioka 2005).

Disposal: Disposal options for e-waste are ranked depending on their perceived level of environmental health impacts as depicted by the waste management hierarchy (Dwivedy and Mittal 2012).

Figure 4.Hierarchy of disposal methods for e-waste (Mmereki et al 2015)

Navigating down the pyramid implies the treatment strategy performed is of increased impact to the environment and human health hence least preferred. (Jofre and Morioka 2005) , edifies to say the hierarchy also indicates the disposal strategies in the order from highest to lowest economic and social efficiency. Therefore by integrating these scholars' opinions the ranking considers the treatment option's environmental health threats, ability to recognize the waste resource value and social acceptability. However, end-of-life (EoL) treatment strategies considered in e-waste management excludes Avoidance and Reduction as they relate to cleaner production at manufacturing stage. Across many countries the acceptable hierarchy of EoL options for environmentally sound disposal of e-waste takes the form of the hierarchy from Reuse and Repair down to Land filling(Jofre and Morioka 2005, Mmereki et al 2015).

Re-use: Reuse is the recovery and trade of used equipment or their parts as originally designed. The procedure involves extraction of components from equipment without resale value so as to reuse them in remanufacturing and refurbishing towards upgrading product quality and durability. According to (Dwivedy and Mittal 2012) , Reuse reduces virgin raw material demand by a third and the energy consumed by a computer along its useful life is as little as a quarter of the energy required to make a new computer.

Recycling: Electronic waste recycling involves the breaking down of end-of-life equipment into secondary raw materials hence re-circulated back as raw materials during manufacturing. Recycling reduces the demand for virgin raw materials that are otherwise extracted through energy intensive processes. Retrievable materials are plastics and precious metal such as palladium, copper and gold. Recovery of these valuables can be a profitable venture resulting into a global trans- boundary trade of the e-waste. According to (Uddin 2012), environmental sound recycling of e-waste is done at three treatment levels. Each treatment level consists of unit operations such that the treated waste from one level becomes the input for the next level. Therefore the efficiency of the first and second level treatment operations determines the quality of residues going for Treatment Storage and Disposal Facility or incinerated after the third level.

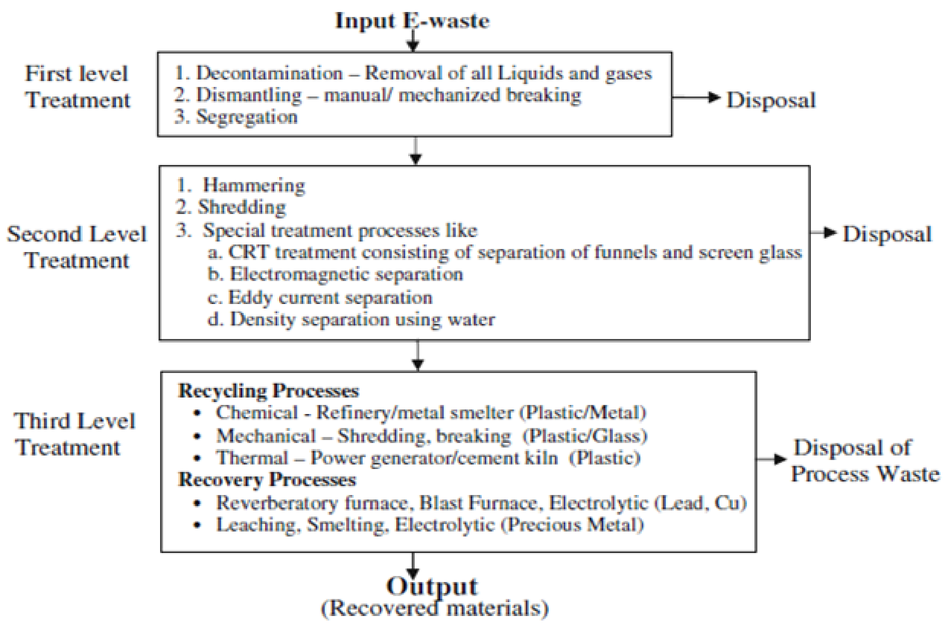

Figure 5.Three treatment processes during e-waste recycling (Uddin 2012)

Incineration: According to Eurostat in (Liebmann 2015), incineration involves the reduction of material volume and their hazardous nature to yield inert products that are safe to discard. Adding to that, the process is ideal for that waste which is not recyclable hence such waste is transformed into energy oxidation. This can be a thermal process to generate heating and electricity using hygienic and environmentally safe methods. The incineration by products include bottom ash that is usable as gravel or land filled and fly ash that can be used to neutralize empty mines or land filled (Liebmann 2015).

Land filling: Land filling is a treatment method usually done when recycling is not appropriate or possible. Pre-treatment is first done to avoid leachates or runoff hence storage of waste in a controlled manner such that it remains safe for years, European Union restrictions in (Liebmann 2015). However, failure to follow the procedure exists as open dumping which yields risks of harmful exposure to residents and their environment.

Storage: According to (Emmanouila et al 2013), storage is not an end-of-life treatment option but rather an intermediary stage within a product lifecycle before the owner of equipment eventually opt for other alternative treatment methods. (Liebmann 2015) , justifies storage as an essential delaying tactic for reuse, incineration, or other treatment options. Furthermore the phenomenon is contributed by several behavior dynamics such as unawareness of proper disposal methods, emotional attachment to gadgets due to perceived value of it.

3.8 E-waste management in Zimbabwe

In the Zimbabwean context, there are no e-waste management strategies whatsoever to deal with the accumulating the e-waste menace. Most of the electrical and electronic equipment (EEE) products are not locally manufactured but rather imported and sold to local wholesalers and retailers who then sell to other consumers. Amongst the imports are used electrical and electronic equipment (UEEE) which are of reduced life span hence end up stockpiled. However, with time the obsolete equipment end up disposed in open dumps or taken by informal collectors who engage in inefficient recycling processes for metal recovery.

4. Research design

A case study design strategy was adopted in this study so as to carry out an in-depth research towards the development of a sustainable e-waste management system in the case study industrial area, Harare. The work was broken down into 2 parts: Analysis of current e-waste management situation and development of an e-waste management framework. A research methodology framework was designed to acquire information on the current e-waste situation in the area. Research instruments incorporated in the data collection framework were observations, reflection field notes and pictures, research questionnaires composed in systematic way. The main aims of the analysis were to assess if organizations have e-waste related policies in place, whether their asset disposal policy include electrical and electronic equipment, to understand how organization manage their end of life electronic equipment and the associated impacts to their methods of management. Therefore, the analysis allowed the researcher to clearly show the detailed information on the generality of the current e-waste management methods and discover challenges that require comprehensive and practical solutions.

5. Case study

The case study industrial area is Graniteside. It is estimated to have a capacity to host above 500 various industrial operations. Graniteside industrial area is characterized of light industries in a locality built up of good road systems for vehicular circulation interlinking the industries. The industries are mostly consumer-oriented since most of the products are done for end users and not as intermediates for other industries. The identifiable industries in Graniteside can be broadly classified into manufacturing, processing, re-cycling and service industries. The manufacturing and process industries in the locality are mostly involved in the production of food, textile, chemicals, plastic, paper and building material. Adding to that, the service industries cover activities such as transport, banking, retailing/wholesaling, consultancy, funeral, security, motor repairing and construction. Recycling companies are mostly in metal scrap, paper and plastic. Solid waste generated consists of a wide spectrum of non-liquid materials such as bottles, food garbage, construction debris, machining waste, paint residues, sludge and oil contaminated components. There is evidence of inconsistent waste collection, transfer and disposal system presently being experienced. The infrequently waste collection is in time leading to surplus waste which is normally dumped on roadsides, open spaces and storm water drains. Adding to the already existing solid waste menace is the newly emerging waste stream of electrical and electronic waste or e-waste. E-waste is one of the advent and growing solid waste type in the local industries hence not yet identified as significant for categorization. The case study area has experienced electrical and electronic equipment uptake being on arise since the dollarization era in 2009.The growth in economy over the past years has given industries the dollar power to periodically import better technologies to replace the older ones hence attaining improved productivity and efficiency. However, most of the imports are counterfeits of reduced life spans and high obsolescence rate from countries such as China and Dubai. Adding to that, availability and affordability of the electrical and electronic equipment on the market is pushing these industries not to hesitate to upgrade their equipment to meet the technological advancement. For that reason, the industrial community is facing increased e-waste inventories due to their obsolete electrical/electronic equipment and components. The two major sources are the service industries and manufacturing industry.

Service industry: These are mainly made up administrative, customer service and marketing department. Therefore, e-waste from this sector is greatly generated from the office and building utilities that include computers used in data saving, telephones for communication , printing devices, photocopies, lighting equipment, heaters, fans, air conditioners and refrigerators as shown in Figure 6.

Figure 6.Obsolete heaters and telephones ready for disposal (Zimba 2017)

Manufacturing and processing industry: The majority of the entities in the manufacturing and processing sector in Graniteside also engage in the wholesale business of finished products. However, the influence of such structure in e-waste generation is that, the operations department produce waste related to the electrical and electronic equipment and components used during production, for instance inductive devices such as motors in drive systems, generators, inductors, capacitors, transducers and sensors in control systems. Currently, e-waste is treated as general municipal waste, and no special attention is given to the activities related to its collection, handling, dismantling and recycling. Most of the activities related to the e-waste collection, handling, dismantling, and recycling are mainly being performed by the unorganized or informal sectors lacking the technical and infrastructural abilities and knowledge about the serious implications of the e-waste handling and disposal on environment and human health. The characterization, quantification and flow of e-waste is unclear as well as the stakeholders currently involved in e-waste handling. Principally, municipal solid waste management in Graniteside is liable directly to the local authorities' responsibility. They are responsible for the collection, transportation and disposal of industrial solid waste. However, such traditional methods of solid waste management cannot be deemed compatible with e-waste. The industrial solid waste management framework in Graniteside has proved not to accommodate for e-waste. E-waste is made up of retrievable valuable engineering materials such as metals and non-metals as well as high concentrations of hazardous substances such as lead and mercury that contaminate the environment. Adding to that, no accurate information is known on the generation, quantification, characterization and management of e-waste in the area.

6. Findings and observations

As presented by Figure 7, 13 out of 32 questionnaire were returned by service industries hence the response rate was 40.6%.In the manufacturing and process industries 19 of 37 questionnaires were returned hence the response rate was 51.3%. Overall, the response rate was 46.4%. However, the response rate was fair considering the fact that the majority of the companies did not give a favourable response with others not even responding to the questionnaires.

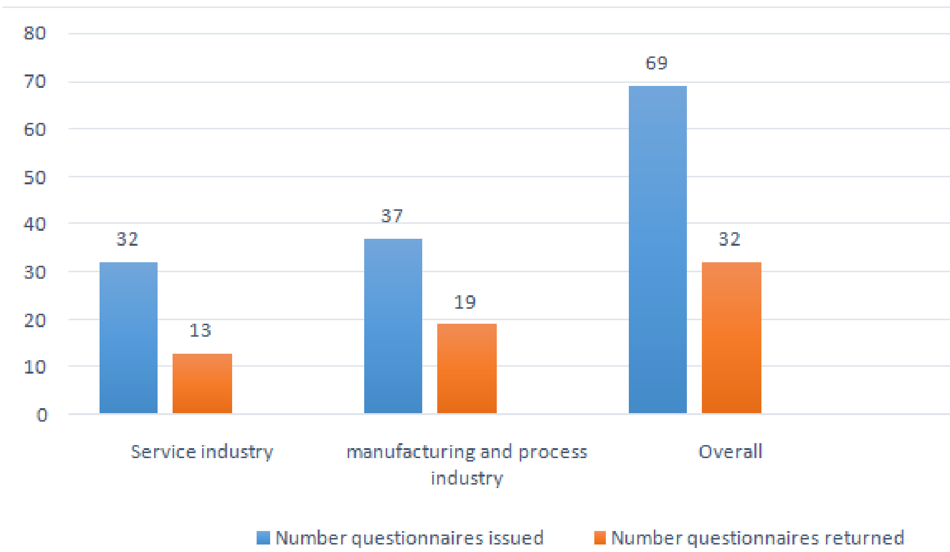

Figure 7.Questionnaire distribution and response rate (Fieldwork 2018)

The composition of the e-waste generated in the industrial area was as follows:

Service industry: The organizational structure of most service industry entities is mainly consisted of administrative, customer service and marketing department. It was shown that, fluorescent lights held the largest share at 35% followed by personal computers (mainly desktops) at 29%, printers and photocopiers at 12%, air conditioners at 9%, phones at 7% refrigerators at 6% and others at 2% which include batteries. The findings resonant with fact that lighting equipment is of shorter lifespan and that lighting equipment are popularly used in industry to enhance task performance and improve the appearance of working areas. The high share of personal computers, printers and photocopiers also echoes with the findings by (Emmanouila, , et al., 2013), that information and technology penetration is increasing with the increase in inbuilt obsolescence in the equipment. However, computers are of essence in service industry as they are used in data capturing in inventory management, information exchange through emails and printers/photocopiers find use in producing tangible data from the computer devices.

Manufacturing and processing: The general organizational structure of the manufacturing and processing sector covered the service related department (Administration, Marketing and Finance) and the manufacturing or process department (Operations). Therefore, manufacturing and processing industries were found to produce the same waste

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types as in Service industry as well as the e-waste due to the operation activities in manufacturing and processing which are mainly passive components in electrical circuitry.

It was noted that fluorescent lights held the highest composition at 28% followed computers at 18%,passive components at 17%, photocopiers and printers at 15%,air conditioners at 11%, refrigerators at 9% and other at 2% which include batteries, sensors and transducers. The above findings resonates with the observation made by the researcher in that, most drive and power systems in manufacturing and process industries utilizes passive components like capacitors for energy storage and power factor correction, resistors, and inductive devices such as motors which easily succumb to wear and tear. In addition, the large share of e-waste consisted of lighting equipment dominated by fluorescent tubes, desktop computers used in automated machinery and data capturing, telephones as well as refrigeration and air conditioning equipment e.g. freezers and chillers used in beverages and food processing industries. Lastly, batteries from industrial utility machines such as forklifts and from uninterrupted power supplies (UPS) used in Programmable Logic Controllers (PLC) and computer backup systems.

All respondents confirmed that no formal e-waste collection and treatment is underway in the industrial community. Therefore, the handling of e-waste generated is entirely the responsibility of the producer of such waste. The survey done in the industries showed that only 10% of the respondents had a regular procedure to handle e-waste whilst 90% had none. Majority even highlighted that they lack no knowledge of their e-waste inventory. The findings concurs with those by (Feresu 2010), thus highlights the need for local consumers of electronic and electrical equipment to have regular e-waste procedures since e-waste comprise of hazardous substances such as cadmium ,mercury and lead which can affect the environment. However, the majority of the companies operating without regular e-waste handling procedures further highlighted to be engaging in various ways to dispose of their obsolete equipment. It was also noted that 53% of the companies store their generated e-waste, 27% throw away with regular waste where the e-waste end up incinerated by scavengers, none of the companies submit their e-waste back to the supplier or for recycling and 20% of companies rely on other disposal methods such as auctioning to employees and other people. The findings go hand in hand with those of (Zunguze 2010) in that, most corporate consumers resort to storage of e-waste due to procedures in writing off equipment. Furthermore, those who attempt to dispose of their e-waste lack knowledge on segregation of the hazardous waste from regular garbage. The finds also resonant with those of (Kojima et al., 2009) in that, most developing countries lack the original equipment manufacturers representatives hence no take systems are initiated. The respondents entirely agreed that the industries and the country at large have no policies or legislations related to e-waste. Nonetheless, there exists the Environmental Management Act (20:27) that forbids the discharge of hazardous substances into the environment but then there is no specificity to e-waste mention. However, they are international standards on environmental management that exists so as to govern industries towards a sustainable environment i.e. ISO 14001.

An assessment was done to determine the general idea on probability of occurrence of the substances hosted by e-waste materials in industries. Copper had the highest portion known to be present in e-waste at 94% whilst followed by polyvinyl chloride at 90%, flame retardants were at 88%, aluminum at 84%, iron and steel at 75% then lastly lead was the least known to occur at 72%. Amongst the suspected to be present, nickel was leading at 68%, cadmium at 60%, mercury at 28%, PVC at 8%, gold at 7%, copper at 4% and lastly iron and steel at 3%. Adding to the above, the substances suspected to be absent include mercury at 4%, gold at 2% and the rest at 0%. Lastly, no substance was known to be absent from the identified e-waste substances under assessment. Lead, PVC and copper are the highest occurring compounds by composition in e-waste. Other compounds such as mercury, chromium, cadmium, and nickel are also known to be present

Majority of the respondents highlighted that area open dumping of e-waste with general municipal solid waste is prevalent. Majority of the e-waste included small components such as plastic casings, lighting devices such as fluorescent tubes and batteries. As no segregation is practiced at the source of disposal, the e-waste components are being incinerated with the general municipal solid waste. Therefore, the environmental risk at hand is that, these components are known to host pollutants which include Brominated Flame Retardants (BFRs) in plastics, mercury in fluorescent tubes and heavy metals such as lead and nickel in batteries hence air pollution, soil leaching and contamination of water sources. However, awareness on the potential recovery of precious metal such as gold from computers and phones is not yet known of which it is a profitable venture that can generate revenue for the government through taxes in the case that the e-waste recycling business is formalized.

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85% of the respondents from the companies under survey confirmed that they are aware of the existence of e-waste whilst 15% had no idea about e-waste. The high percentage of companies aware of e-waste was based on that most of maintenance personnel are qualified technicians and engineers. However, it was noted that the majority of the companies unaware of e-waste were mostly service related industries which are dominated by non-technical personnel unlike the manufacturing and process sector. E-waste growth is at a rising and it is one of the huge threat facing industries in e-waste management. According to the survey, the factors leading to fast e-waste growth were ranked as technology 31%, obsoleteness 27%, wear and tear 21%, and industrialization 14% as well as others at 7%. The majority of the industries lacked e-waste handling procedures because of the absence of e-waste strategies as lack of infrastructure 30%, costs 27%, absence of recycling possibilities 23%, lack of legislations 13% and other factors 7%.The findings concurs with (Chitotombe 2013; Zunguze, 2010) who undertook a general survey of the e-waste problem is Zimbabwe. Also lack of coordination between stakeholders of e-waste management was cited as reason for lack of e-waste management strategy. Amongst the stakeholders are the government which could play a regulatory role through agencies like Environmental Management Agency EMA, City Council and Zimbabwe Revenue Authority (ZIMRA). EMA is responsible of policy making, city council is responsible for general waste collection and the ZIMRA is in charge of product inflow from other nations and collect tariffs on legally imported goods. Recyclers could modify their processes to accommodate e-waste materials.

7. E-waste management framework

The e-waste management framework would entail the establishment of e-waste inventory to get a clear knowledge on expected quantities and characteristics of the waste stream prior to the implementation of a management framework (UNEP 2007).The task of taking e-waste inventory remains cumbersome since e-waste products are of different lifespan and are not generated every day. A decision matrix table was used to help determine the applicable method in this case study. Therefore, considering the scarcity of electronic and electrical import and sales data locally, the researchers made a proposal to borrow the consumption and use method to estimate the e-waste quantity. This methodology assumes saturation of electrical and electronic equipment per consumer. For the quantification process, an assumed weight and life-span of the product, and the total number of consumers are considered. This method has been used to estimate potential e-waste generation in elsewhere with great accuracy (Schulep et al 2012). The estimated quantities and average life span of the major equipment in the e-waste stream in the area were considered as per questionnaire survey. Therefore, by applying the consumption and use method to quantify each e-waste product in the industrial area was determined. In the case of developing industries,(UNEP 2007) suggest that the consumer disposal behavior is different such that the determined lifespan of a product has to be modified to cover for the useful time (Active life) + time the appliance can be used after refurbishment (passive life) + time the product is stored before disposal (storage time). Therefore, following the same procedure for all products the yielded results are as in Table 1.

Table 1.E-waste generation rate

Types	**Average mass(mn)/Kg**	**Number of companies(hh)**	**Penetration ratio(rn)**	**Average lifespan(Lsn)/years**	**Estimated e-waste generation rate (tons/year)**
Personal computers	25		1:18	10.4	21.64
Refrigerators	35		1: 2	20.6	4.23
Printers and photocopiers	6.5		1: 14	9.9	4.60
Air conditioners	55		1: 6	22.6	7.30
Phones	1		1:2	10.4	0.096
Total					**37.87**

The potential generation rate of e-waste in the area would be equal the sum of individual generation rates per item thus **37.87 tons per year**. However, it is important to note that on this section of inventory management only e-waste items common in service industries and in manufacturing and process industries are considered.

The design of a collection system is guided by the principles that consumers require reasonable access to collection systems without charge and the program design and implementation will strive for equity and consistency for consumers. (Jenkins , et al., 2003) ranked the collection methods according to the most preferable as: permanent collection (47%), drop off (45%) and curbside collection (8%).Therefore, the researchers identified that the most appropriate approach for collection of EOL electronics is for industrial consumers to bring their e-waste material to permanent collection points that will be set in the locality. However, permanent collection points carry pitfalls in that they shall require costs in storage infrastructure and supervision although the process of mounting such collection points will act as a recycling awareness campaign to the industrial community. Collection infrastructure requires establishment of e-waste collection points and storage area in a geographical region. Basing on this assumption, one collection point is proposed because the number of industries is generally lower than the required numbers to launch one collection site, hence the single collection point can be thought to be favorable to accommodate all. Thus, a central position in the area would be best suited as a location for a collection centre, and such a locality should be easily interlinked to every other industry via a well planned road network. Proper storage is achieved by providing sorting container specific to each e-waste product collected to ensure that the waste is segregated. The researcher proposed that products for cooling appliances such as refrigerators/freezer, display equipment with CRT tubes such as desktop computers, lighting devices dominated by fluorescent bulbs shall be separately stored from all other containers with e-waste materials such as passive components. Containers of appropriate size and shape should be used for segregation of e-waste items to facilitate effective handling. Furthermore, containers can be made either of wood or plastic or mild steel or any appropriate material with sufficient strength for holding the e-waste. Segregation of the collected e-waste components is essential in that, components such as CRTs and florescent lights contain glass hence fragile and easily break to release hazardous substances contained in them such as lead in CRTs and mercury in fluorescent tubes. Adding to that, refrigerators and air conditioners carry the risk of leakage of compressor oils, CFCs/HCFCs if any. Passive components such as transformers, motors and electrolytic capacitors might be containing oils as well hence should be segregated properly to avoid spillages. Impermeable surfaces on the storage area will be a necessity to avoid leachates from e-waste components to penetrate the soil and affect underground water tables.

8. Recommendations

The gaps found by the researchers, included insufficiency in addressing the uniqueness of e-waste and lack of clarity on key stakeholders' roles in e-waste management. A suggested rectified policy will not stop e-waste but regulate its disposal, handling and management infrastructure and processes hence reducing its effects to the health of citizens and the environment. This could be implementable through higher taxes on substandard products or engaging certified distributors of original equipment manufacturers. Licenses could be issued to local recyclers hence initiate development of formal e-waste collection and recovery facilities. The local authorities could also formulate by-laws to manage e-waste at industrial levels such that the uniqueness of the waste in observed and institute proper segregation prior to disposal. Economic and regulatory incentives could be developed to stimulate best practices like importation of green equipment in the industrial environment. There is need to improve awareness level among stakeholders on e-waste handling techniques, economic opportunities realized the resource value of the waste and its hazards due improper handling. The improved awareness ensures for the increased number of participants in the e-waste management system hence effective collection and treatment of the targeted waste. The industrial community therefore requires an e-waste fund establishment to ensure sustainable financing of e-waste management activities. Sustainable funding will ensure proper collection and disposal infrastructure. The waste recyclers need to be given operational license to accommodate e-waste collection and treatment since the recyclers have potential to modify their systems to include e-waste.

9. Conclusion

The outcomes of the study would serve as a model when developing e-waste management systems for other industrial areas. Furthermore the research yielded the required background knowledge for the authorities, when they draft a policy to regulate e-waste. The research would also be an eye opener to the local investors to venture into the lucrative trade of e-waste recycling, a topic hardly mentioned in the local industry. This will enlighten local manufacturers that they can save a lot by reuse of the waste thus reduced sourcing for virgin raw materials as well as energy in processing them. The study raised awareness on the dangers associated with e-waste mismanagement hence saving the environment.

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Biography

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