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Crucial concerns on computing and electronic waste management: from an environmental health perspective

Koleayo Oluwafemi Omoyajowo[a], John Akintomide Ogidan[b], Patrick Chiedozie Akas[c]

Science Policy and Innovation Studies Department, National Centre for Technology Management
An Agency of Federal Ministry of Science and Technology, Nigeria

[a-c]E-mail address: omoyajowo.koleayo@gmail.com , Johnsaic2006@yahoo.com , akas.patrick@yahoo.com

ABSTRACT

The call for a more environmentally conscious society is an emerging issue in today's modern world. Globally, critical concerns about computing and e-waste recycling practices have been raised in recent times. Global warming among other environmental damages caused by computing and inappropriate e-waste management has stimulated the need to rethink environmental impact of information and communication technology. The environmental health consequences of exposure to huge carbon footprints, electromagnetic radiation, and warming heat during computing and environmental contamination during recycling activities in the informal sector are both potentially severe to the ecosystem. Hinged on recent literatures, this article holistically considers the consequence of computing, injudicious dumping of e-waste and inappropriate e-waste recycling practices and offers an understanding of environmentally sound remediation measures to circumvent this menace.

***Keywords*:** Computing resources, e-waste, Global warming, Environmental health

1. INTRODUCTION

In today's modern world, it is practically impossible to envisage the design, operation and maintenance of modern facilities without the use of computers or its application. Computers and other computing resources have an elaborate role in daily life of humans and the leading proof is present at our immediate environment. Vast majority of modern facilities available around us such as global positioning system (GPS), automated teller machine (ATM), cell phones, fax machines, petrol pumps, electronic display boards etc. all uses computer controlling units to conduct their featured operations. They are worthwhile and perhaps relevant in a number of application based services such as banking, medicine, transportation, security, government affairs and even in the education sector. Computing and computing environment both seems to be unique terms in the field of information communication and technology (ICT). In this context, the first term is any process that makes use of computing resources (computers, cell phones, copiers, wireless gargets etc.) or its application to complete a task and the latter, as a collection of computers, software, and networks that support the processing and exchange of electronic information meant to support various types of computing solutions.

Despite the immense relief that ICT has brought in the last 5 decades, computing resources have largely challenged the integrity of the environment due to its hazardous components coupled with the alarming danger of energy shortage in the society [1]. The global effort towards industrial revolution has largely contributed to the growth of electronic markets with new advanced devices, wireless gargets being produced continuously [2]. The justification for this review is based on two cogent reasons. First, the number of consumer electronics has rapidly increased over the years. Secondly, many third world countries lack the appropriate technology, facilities, and resources needed to produce ecofriendly computing resources and manage e-waste. This review further provides logical answers the question "what are the environmental and health impacts of computing and crude recycling activities?"

2. COMPUTING AND E-WASTE LIFECYCLE

Wastes are commonly associated with every stage of computing lifecycle from cradle to grave (i.e. from design, manufacturing, usage to disposal of computing resources).

The need for power efficiency has become a critical factor in the design of high performance computing. Tremendous amount of energy and resources is expended in manufacturing a laptop PC and many other important components such as semi-conductors. For instance, the production process of a desktop computer and a 17-inch CRT monitor requires 240 kilograms of fossil fuels, 22 kilograms of chemicals, and 1,500 kilograms of water [3].

Correspondingly, for the period of using a computing resource, varying amount of electromagnetic radiation, heat energy and carbon dioxide are discharged to the environment. E-waste represents the last stage of a computing life cycle with an array of discarded artefacts such as disused cell phones, cathode ray tube (CRT) televisions, defunct laptop PCs, CRT monitors, liquid crystal display (LCD) monitors, keyboards, fax machines, lead batteries and capacitors etc. at disposal.

E-waste is one of the fastest-growing streams of municipal solid waste in that when old computing resources become obsolete or lack the required functional capabilities, they often end up in landfills or get shipped to third world countries, where these wastes becomes a major environmental and health concern [4]. It is estimated that about 20–50 million tons of e-waste are produced annually worldwide [5,6]. The moving trend which is a loophole in e-waste regulation is the influx of e-waste from developed to developing countries under the guise of "donation" and "recycling" purposes.
Major constraints in e-waste management are summarized below:

a. Poor awareness level is a major challenge for e-waste management in developing countries.

b. Short life span of most electronic products— less than two years for computers and cell phones. For instance, the average life span of computers has reportedly dropped in recent years by 50% from 4 to 2 years [7].

c. Massive production volume and insufficient management policy in many countries across the globe are factors challenging e-waste management [8,9].

d. Due to stricter regulations and the high cost of recycling and disposal of e-waste in developed countries, discarded computing resources in developed countries are packaged and shipped to less developing countries [10]. Cost of logistics and transportation is a challenge faced by most recyclers, preventing the flow of waste volumes in the country.

e. Absence of a well-structured management strategy has resulted in the informal recycling sector polluting the environment and having negative health impacts on humans, aquatic and terrestrial organisms. E-waste in developing countries is largely being managed by informal collectors and recyclers. Disposal options available to a user at the end of the life of a product include either adding it to household waste, giving it away or selling it to informal collectors, or donating it to a family member, school or employee.

The creation and discharge of hazardous components of computing resources often occurs in the so-called "informal" sector of e-waste recycling where crude recycling processes are used and where occupational safety and environmental protection is often not prioritized [11]. The practice of manual dismantling of e-waste components using bare hands and in some cases, stones, hammers, chisels, and screw drivers and open-air-burning of e-waste with incidences of chemical explosions very common in the informal sector. Although, large quantities of e-waste in developing countries (e.g. Nigeria) have created an avenue for individuals to make a living by utilizing unconventional, uncontrolled and crude procedures to recycle and recover valuable metals from this waste. Poor children and women, especially those living in urban areas, represent a large portion of e-waste recyclers and a routine basis, they suffers severe illness related to ingestion, inhalation, dermal contact [11,12].

Unfortunately, most people in this category are unaware of the potential dangers of the crude recycling of e-waste; this draws public health concerns. The methods of disposal (such as landfills and incineration) of e-waste are a major environmental issue affecting climate change. In the United States, only about 18% of e-waste is collected for recycling, with the remaining 80% sent to landfill and 2% for incineration [13]. Landfill can cause leaching of toxic metal from the e-waste into soil and water thereby impacting on biological organisms (including humans) through the food chain [14].

Persistent organic pollutants (e.g. polychlorinated biphenyls), dioxins (polyaromatic hydrocarbons) and vast majority of heavy metals may be released to air, dust, soil, food and water. Levels of heavy metals, PCBs and other toxicants have seen to be higher than their

permissible limits in e-waste recycling areas. The measurements of these toxic substances in human blood [15] serum or human hair [16], urine [17] have been reported above the allowable or acceptable limits in areas of e-waste processing. In fact, decreased lung function has been observed in boys aged 8 to 9 years living in an e-waste recycling town but not in boys living in a control town [18]. To a large extent, subsequent ecological disturbances arising from environmental contamination including food poisoning may result to loss of biodiversity. Biodiversity which generally refers to the variety and variability of life on Earth is essential for natural sustainability for all life forms.

3. MAJOR POTENTIAL HAZARDOUS COMPONENTS OF COMPUTING RESOURCES

In general, computing resources or electronic products are made of a multitude of components, many of which contain deadly chemicals. These chemicals are a strain on human health and the environment. Most of the components in electronic devices contain lead, cadmium, mercury, and halogenated compounds etc. Heavy metals and halogenated compounds appear to have a major influence on potential health risks for humans [19]. The potential adverse health effects of exposure to hazardous chemicals produced by e-waste recycling may have carcinogenic effects and endocrine disrupting properties that could lead to lifelong changes due to neurodevelopment anomalies, abnormal reproductive development, intellectual impairment, and attention difficulties [20].

3. 1. Lead (Pb)

Pb is a naturally occurring toxic metal found in the Earth's crust. Its widespread use has generated significant environmental health problems in many parts of the world due to its long half-lives. It is perhaps the most-studied developmental neurotoxicant and one of the principal toxicants in e-waste. It is basically a component of a typical old CRT television, CRT computer monitor [21] and in soldering unit of printed circuit boards [22]. Studies have shown that children residing in a primitive e-waste recycling site tends to have mean blood Pb level of about 15 μg/dL compared to the neighboring control site (~ 10 μg/dL) [23,24].

High Pb exposure in childhood has been associated with neurodevelopmental deficits in children, delinquent behaviours and criminal activities in adolescents and young adults [25,26]. The mechanism of Pb toxicity shows that Pb increases the formation of superoxide anion ($^{\cdot}O_2^-$) and hydrogen peroxide (H_2O_2) in the central nervous system (CNS), which may interact with proteins, lipids, and DNA to induce apoptosis [27].

3. 2. Mercury (Hg)

Mercury is a naturally occurring toxic element that is found in the ecosphere. It is mostly used in laptop monitors, cold cathode fluorescent lamps, cell phones, and printed circuit boards (e.g., switches, relays). It is released into the environment from volcanic activity, weathering of rocks and mostly as a result of human activity. Improper recycling of e-waste may release Hg in its elemental vapour form into the environment [28]. The implication of Hg influx is that in water bodies, some bacteria have the ability to transform inorganic Hg to organic methyl mercury (MeHg) in a process termed biotransformation. Aquatic life forms bioaccumulate MeHg in their tissues.

Hg toxicity largely affects the food chain. Since, Hg has a long term toxicity effect, ingesting MeHg-contaminated fish could be detrimental to consumers and living things co-habiting in e-waste recycling sites. MeHg affects the mitochondria electron transport system and causes overproduction of ROS [29]. Large predatory fish are more likely to have high levels of mercury as a result of eating many smaller fish that have acquired mercury through ingestion of plankton. Hg exposure from e-waste may stimulate neurodevelopmental effects in pregnant women and children.

3. 3. Cadmium (Cd)

Cadmium is also naturally present in the ecosphere though classified as a probable carcinogen and endocrine disruptor [30]. It is used in nickel–cadmium (Ni-Cd) batteries, surface mount devices chip resistors, infrared detectors, and semiconductor chips [22]. E-waste contains high fraction of old rechargeable batteries, rich in Cd. Toxicological studies have reported that chronic inhalation of cadmium causes pulmonary adenocarcinomas [31] and dietary exposure Cd levels exceeding permissible limit is associated with renal, prostrate and ovarian cancers [32]. Living in an e-waste recycling site substantially increases exposure of children to Cd. Due to long half-lives that Cd has, children in Asian countries where the general populace mostly consume rice and tobacco smoke are at higher risk than children in western countries [33].

3. 4. Hexavalent chromium (Cr (VI))

Cr (VI) is used in metal coatings of some electronic devices for corrosion protection. It is a known human carcinogen after occupational inhalation exposure, but its toxicity in foetuses and children after environmental exposure is largely unknown [34]. Oxidative stress in hypothalamus and anterior pituitary has been reported in Cr-exposed animals [35]. E-waste recycling can result in high Cr exposure in foetuses, with one report of mean cord blood Cr of 99 μg/L, significantly higher than the control-site mean of 32 μg/L [36].

4. COMPUTING AND GLOBAL WARMING

Utilizing computing resources effectively, improving environmental performance through environmentally sound practices and defending global warming are in priority on the list of global challenges that must be addressed urgently. Mass production and extensive usage of computing resources (personal computers, copiers, cell phones etc) contribute to global warming. Incineration or burning of e-waste as it is mostly practised in several developing countries may generate extremely toxic dioxins and furans which may cause lung cancer and other respiratory illness to people residing at recycling sites [5,8,37]. Hence, the vaporization of volatile substances into the atmosphere during these activities presents a threat to the environment. Moreover, the resulting carcinogenic emissions may add to the alchemy of harmful gases contributing to climate change.

Carbon footprint which represents the total set of greenhouse gas emissions caused directly and indirectly by an individual, an organization, an operation or a product is responsible for global warming [2,38]. Greenhouse gases (GHGs) includes carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6) and fluorocarbons. Global warming describes a gradual increase in the average temperature of the Earth's

atmosphere (14-15 °C) and its oceans, a change that is believed to be permanently changing the Earth's climate due to several anthropogenic activities (e.g. burning of fossil fuel) [39]. Its deleterious effect includes frequent harsh weather, high mortality rates, poor air quality, higher wild life extinction rate, aquatic life devastation, melting of the polar bears leading to flood [39,40].

There is no gain saying that computers and its related resources consume much power (electricity). Recent study has shown that computing resources are the largest sources of growth in electricity demand in commercial and government buildings [41]. For instance, a typical medium-sized personal computer consumes about 150 Watts of electricity per hour. This pushes the electricity usage high, especially in a situation where computers are not switched off after use. CO_2 fossil emissions are directly correlated with energy generation and consumption. The industrial revolution was sustained by fossil fuels that drove carbon extraction and combustion, with its subsequent effect on the climate.

5. COMPUTING AND HUMAN HEALTH

5. 1. Effect of computing on human reproductive health

The increased use of computers, at home or at workplace bring forth a number of health concerns. One of these health concerns is the human reproductive health. It has been reported that long term use of a laptop PC on the lap may possibly affect male reproductive health, reducing sperm quality and enhancing tumour development in testis [42]. The warming heat from laptop PCs can denature men's scrotums, the electromagnetic fields generated by laptop's internal electronic circuits as well as the Wi-Fi Radiofrequency radiation hazards (in a Wi-Fi connected laptop) may decrease sperm quality.

5. 2. Computing and Cancer risk

Computers, cell phones, wireless gadgets and many other electronic devices generally generate both low-frequency and radio-frequency electromagnetic radiation (EMR) which are potential carcinogens. EMR causes oxidative stress in the body, a reaction which releases free radicals—molecules that can cause cellular damage unless they are removed by antioxidants. Although many studies have examined the potential health effects of non-ionizing radiation from radar, microwave ovens, cell phones, and other sources, there is currently no consistent evidence that non-ionizing radiation increases cancer risk [43].

Alarming levels of dioxin compounds in the environment caused by inappropriate disposal of electronic products have been linked to cancer and other developmental defects [44]. More so, a recent study suggests that non-ionizing radiation from laptops can trigger tumour development in pregnant women and foetus [45].

Older CRT (cathode ray tube) monitors could emit X-ray radiation, but in small amounts. Prolonged usage of older CRT monitor for instance, can affect users' visual sense and could possibly cause a diminished intellectual capacity. Data linkage study of 11 million Australians clearly shows that ionising radiation from diagnostic computed tomography (CT) scans increases the risks of cancer [46] due to high radiation dose.

5. 3. Effect of computing on glucose metabolism

Glucose metabolism is an essential cellular process that occurs in humans and most living organism for growth, survival and continuity of vigour. It has been suggested that radiofrequency energy from cell phones might affect glucose metabolism [47]. Radiofrequency energy could either increase or decrease glucose metabolism in the region of the brain closer to the antennae of cell phone [48,49]. The rise or fall of body glucose level may be severe with individuals with hypoglycermia (patients with low blood glucose levels) or hyperglycermia (patients with high blood glucose levels).
The discharge of some toxic metals (mercury, lead and cadmium) can induce oxidative stress by increasing the production of reactive oxygen species (ROS) and depletion of antioxidant reserves [26].

5. 4. Others

The amounts of dioxins and furans as reported by can cause irritation of the eyes, nose and throat [16,50]. Heavy metals are well known or suspected to have developmental neurotoxicity in humans especially children [50]. Intelligence quotient, memory loss, language, gross and fine motor skills, attention, executive function and behaviour have been observed as some effects of neuro-developmental deficits caused by excessive intake of trace metals [51]

6. ADDRESSING COMPUTING AND E-WASTE MANAGEMENT PROBLEM

a) Creating financial incentives for recyclers operating in the informal sectors to deliver recovered parts to central collection sites rather process them.

b) Creating an enabling environment for green trade and marketing initiatives such that individuals, groups or organizations can equally trade and market their obsolete or defunct computing resources in exchange for a new, functional green compliant product.

c) Creating public awareness on the hazardous nature of e-waste and crude waste management techniques used in developing countries. Creating green jobs for people in the recycling areas: for instance, Bioleaching of E-waste, a green technique that uses biological organisms to recycle metals in e-waste [43]. Mainly acidophilic group of bacteria plays an important role in bioleaching of heavy metals from the wastes for instance Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidans, Leptospirillum ferrooxidans, and Sulfolobus sp. [43]. Bioleaching is based on the natural ability of microbes to transform solid metallic compounds to its solubility and extractable form. Microorganisms have a tendency to extract metals from its sulfide and or iron-containing ores and mineral concentrates. Pham and Ting (2009) extracted Au from E-waste by utilizing cynogenic-bacteria (Chromobacterium violaceum and Pseudomonas fluorescens) along with a pretreatment for bio-oxidation of E-waste by A. ferrooxidans (which specifically remove Cu leaving Au residues behind) [52,53].

d) Many other green jobs with the interest of environmental protection should be provided for people with less economic opportunities.

e) Enforcing legislation and labour standards, eliminating practices which are harmful to human health.

f) Extended producer responsibility (EPR). EPR should be considered as the most promising means to combat the increasing waste generation and pollution. Extended producer responsibility (EPR) is an environmental protection strategy that makes the manufacturer of the product responsible for the entire life cycle of the product. Appropriate design and ecofriendly manufacturing processes should be tailored towards extending the life span of computing resources. This will relieve governments' financial burdens in managing e-waste and provides incentives for producers and manufacturers to reduce waste by reusing secondary raw materials from waste and continuously improving their products and processes.

g) There is should be an urgent demand for cost-efficient treatment systems that optimally harness the valuable fractions in a more environmentally sustainable manner [54].

7. CONCLUSIONS

Computing is inevitable and e-waste recycling is necessary so therefore green policies that would provide incentives to promote safe, regulated and recompensed recycling for e-waste should be made across all sectors. Green computing initiatives such as appropriate recycling of e-waste can keep harmful materials (e.g. lead, mercury, and hexavalent chromium) out of landfills, and can also replace equipment that otherwise would need to be manufactured, saving further energy and emissions. Research needs, educational and awareness programs on the potential risks of e-waste recycling also should be developed and implemented. Incentive-based policies that protect human health and the environment must be proactive and practical. Research that will help informal local, regional, and global e-waste recycling policy is urgently needed.

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