



Effects of Electronic Waste on Developing Countries

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Abstract

Although developed countries are currently producing large amounts of electronic waste (e-waste), the rate at which e-waste production is growing in developing countries is a major concern. The unsafe disposal of this e-waste is a growing problem and the environmental effects and human health hazards are very serious. A plan needs to be established to address this issue and in order to avoid these environmental and health consequences. This paper addresses the causes resulting in the exportation of e-waste to developing countries, the environmental and health effects resulting from this disposal, and possible mitigation strategies to address this growing environmental justice issue. Several recommendations are proposed. First, instead of trying to abolish the informal sector within these developing countries, it would be beneficial to take advantage of the collection network that the informal recycling sector has created. An incentive system will most likely be needed in order to establish the connection between the informal and formal recycling sectors. The informal recyclers will then be more willing to bring their collected e-waste to the formal facilities where it will be treated properly. Lastly, manufacturers and producers need to become more involved by implementing more successful take-back systems for their electronic devices so that they will be recycled properly at formal facilities that will mitigate the negative environmental and health impacts.

Keywords: Electronic waste; Disposal; Recycling; Health impacts

Introduction

Electronic waste or e-waste is the term given to describe any electronic product, or product containing electrical components, that has reached the end of its usable life cycle [1]. When these products are deemed to be at the end of their usable life cycle and thereby become e-waste, proper disposal is essential due to the harmful materials many of these items contain. E-waste production is increasing at an alarming rate, especially in developing countries which currently do not have the proper funds or resources to dispose of it properly. Many developed countries find it cheaper and more convenient to ship their e-waste to these developing countries, which only adds to the amount of e-waste undergoing unsafe disposal. Without proper disposal, chemicals such as lead, arsenic, chromium, and dioxins may leach into the environment, causing environmental degradation and pose a threat to humans and animals in the vicinity. Unsafe disposal of e-waste is a growing problem and the environmental effects and human health hazards are very serious; a plan needs to be established to address this issue and avoid the consequences.

Background

The problem of e-waste is escalating rapidly through increased production of electronics and e-waste exportation from developed countries to developing countries because of the beneficial economic incentives that it provides. The total amount of e-waste produced has reached approximately 41 million ton in 2014 and increasing at a rate of 3-5% every year [2].

Escalating problem

Technology is advancing at an exponential rate; new electronics are faster, smaller, and more convenient to use. What about that old phone, computer, or camera that is discarded because there are newer and fresher alternatives? We live in a consumer driven society that is constantly buying, upgrading, and replacing current technology.

Production: Not only are we replacing the technology that we already have, but the sheer number of new electronics per household is growing to keep up with and maintain the modern lifestyles we have created through the use of these products. The growing amount of produced electronic devices translates to a large increase in e-waste production. In fact, it is estimated that by 2017, global e-waste production will increase by 33%, which is approximately 72 million tons [3].

It is estimated that the U.S. produces 400 million e-waste items a year on its own. European Union and Japan household e-waste production are estimated at 8.9 million tons and 4 million tons respectively, and these e-waste volumes are only expected to increase [1]. Although developed countries are currently producing large amounts of e-waste, the rate at which e-waste production is growing in developing countries is alarming. For example, in India, e-waste reserves are growing at a compounded annual growth rate of 25 percent [3]. This translates to an increase in the amount of e-waste that will undergo unsafe disposal in the future if significant changes are not made.

Exportation from developed countries: Prior to the 1970's, very few places in the world had strict regulations pertaining to the disposal of hazardous waste; dumping the waste into landfills was a very common practice. However, over the course of the 1970's, many developed countries began to approve regulations that managed the treatment of hazardous waste and chemical use in the environment such as the toxic

substances control act, clean water act, and clean air act. In compliance with these new regulations, companies producing hazardous waste were forced to spend more time, money, and resources to dispose of it properly. This induced many hazardous waste producing businesses began to search for alternatives as to how to dispose of the waste at a lower cost [1].

Until the middle 1980's, almost all of the hazardous waste (including e-waste) produced in the US and Europe stayed there. However, in the late 1980's, US and European companies began to apply for UWEPA approval. This approval granted these companies permission to ship hazardous waste to developing countries overseas. Although there were regulations limiting the type of waste that could be exported, shippers of the waste found ways to get around the system. For example, waste exporters would intentionally mislabel waste containers with names incorrectly classifying the waste. This loophole allowed more hazardous material into these developing countries [1].

Developing countries leading the pack in accepting e-waste from the developed world today include China, India, Pakistan, and Nigeria [3]. These destination countries have established several businesses that dispose of the waste without proper government oversight. Though there are regulations, local authority figures generally do not see e-waste as a high priority and in many cases ignore the issue. Many of these developing governments see the immediate economic incentives and fail to acknowledge the potential negative effects of unsafe disposal.

Economic incentives: When developed countries such as the US began shipping their e-waste to developing countries in the late 1980's, receiving nations started to form a new business sector that disposed of the waste without proper regulations, equipment, or safe disposal techniques. These businesses created jobs for people in these developing countries, and helped support many poor families. The governments running these countries also had financial incentives to accept e-waste from developed nations. For example, China's government established a collecting fee of \$50 US currency per ton of waste collected [1]. Economically, the exchange was a win-win for both sides. Businesses in developed countries are able to ship their e-waste to developing countries at low cost and no longer have to keep up with strict disposal practices in their own countries. On the other side, developing countries have financial incentives to accept the waste, and the disposal business has created much needed jobs.

Economically, this exchange works well for both sides. However, these incentives to ship waste to developing countries only adds to the amount of e-waste undergoing unsafe disposal practices and causes several other issues pertaining to human and environmental health.

Current practices in developed and developing countries

The two major types of e-waste recycling methods that are used throughout the world are formal and informal e-waste recycling. Formal recycling primarily occurs in more developed countries due to the increase in the costs necessary to use this method. It costs more money to recycle the e-waste properly in a formal facility than to recycle the e-waste informally. Informal recycling facilities are primarily used in developing nations.

Formal recycling practices: In developed countries, formal recycling practices are taken very seriously. These e-waste management systems are comprised of three components: the national registry, collection systems, and logistics. The registry can be monitored by a variety of agencies and is essentially a list of e-waste producers with attached

collection obligations. As for collection, there are two main types for e-waste in developed countries: collective systems and clearing house systems. Collective systems are nonprofit and typically founded by trade associations. The focus of this type of collection system is on the sorting and channelization of each e-waste type to the appropriate division for reuse. The clearing house system is run like an auction with the government providing the national registry, allocation, producer obligations, and collection points. In the clearing house collection system waste businesses, producers, and recyclers all participate with the hopes of providing their services. As for the logistics of e-waste disposal there are three main avenues: collection by municipal collection sites, in-store retailer take-back schemes, and direct producer take-back. Once the e-waste is collected dismantling, pre-processing, and end processing occur to ensure safe disposal or recycling of e-waste. Dismantling and pre-processing only require minimally skilled workers capable of performing mechanical processes with drills and wrenches. End-processing requires highly skilled workers and complex equipment such as integrated metal smelters which can be very costly. These intricate systems have been designed such that the handling and disposal of e-waste has minimal impact on the environment. However, these facilities can cost hundreds of millions of dollars to construct and operate. This formal recycling process has proved to be effective, but finding a way to apply these techniques in developing countries poses financial challenges [1].

Informal recycling practices: Ideally, all e-waste should be recycled in formal recycling facilities. However, because the formal e-waste facilities are costly to construct and operate, especially in less developed countries, informal recycling sites are prevalent. The informal e-waste sector consists of sites that extract the valuable parts of the electronics using crude recycling and disposal methods usually without any kind of safety equipment such as goggles or gloves or the assistance of technology [4]. Families and other individual workers in these communities depend on the extraction of the valuable metals from e-waste for their livelihood. Some of the valuable materials are removed primitively and the remaining parts of the e-waste are typically burned, buried or discharged into waterways for convenient disposal [1]. These crude procedures used in the informal sectors are what lead to environmental contamination because the processes emit toxic chemicals from the e-waste into the surrounding environment [5].

The most common crude operation is open-pit burning to remove electrical components and valuable metals from circuit boards and other e-waste which commonly results in the release of toxic chemicals such as polycyclic aromatic hydrocarbons (PAHs) and halogenated PAHs into the air and surrounding environment. Improper incineration and the burning of cables to recover metals is also performed creating different types of dioxins which are extremely toxic compounds that can be very difficult to remove [6]. Open acid bath procedures are also common where acid is used to strip metals from the electrical components [7]. The used acid from acid treatment procedures becomes filled with heavy metals and other toxic chemicals and is typically dumped into the surroundings creating another environmental hazard. Additional pollutants can be exposed to the environment from e-waste being physically dismantled, buried or dumped into the environment [1]. E-waste informal processing sites can be located near agricultural fields and other cropland where heavy metals and other pollutants can penetrate into the soil where food is grown [5].

Environmental and Human Health Effects of E-Waste

Informal recycling causes severe environmental and human health effects that need to be addressed and controlled. This section focuses on specific examples and studies that have been conducted on recycling e-waste in countries such as China, Nigeria, Philippines, Brazil, etc.

Toxic Chemicals in E-Waste

A recent study showed that Au, Pb, Ag, and Sb were found in the soil at an informal e-waste recycling site in Philippines [8]. Electronic devices contain a plethora of components and parts, many that house portions of toxic chemicals that are harmful to humans. Chemicals can originate from large household appliances such as refrigerators, washers, and dryers. Consumer equipment is also a large portion of electronic waste and includes TVs, cell phones, computers, monitors, and even sporting equipment. The parts that make up these devices often contain hazardous chemicals that in turn end up going to developing countries. Some of these component that contribute to the toxic waste include batteries, circuit boards, cathode-ray tubes, and lead capacitors [9]. The majority of the e-waste is comprised of iron and steel (50% of waste). Plastics and ferrous metals make up the next 21 and 13 percent, respectively [10]. However, many of these components contain toxic compounds like PCBs, dioxins, and heavy metals in their elemental forms. Lead, Cadmium, Nickel, and Lithium alone are found in used batteries, much like the ones being mass-produced in electric vehicles. Organophosphate flame retardants and plasticizers in urine samples of the people living in an e-waste dismantling site [11]. Trace metal contaminants from e-waste soils but not in the effluent due to adsorption to Fe/Mn oxides in the sub-layer soil [12].

Information technology is a key player in the production of hazardous chemicals that come from a variety of components, mainly computers. One study done on the impact of hazardous e-waste in India has estimated that over 30,000 computers have become decommissioned each year in Bangalore alone. The high disposal of computers has cultivated more than 1,000 tons of plastics, 300 tons of lead, 0.23 tons of mercury, 43 tons of nickel, and 350 tons of copper in Bangalore [10]. In Bangladesh, at a shipyard in Chittagong, contamination plagued the nearby soil from chemicals that are commonly found in electronic waste. Soil samples contained compounds such as "lead, mercury, cadmium, arsenic, antimony trioxide, polybrominated flame retardants, selenium, chromium, and cobalt" [13].

Victims in developing countries are exposed to hazardous chemicals in a variety of ways. Victims of electronic waste can be affected by direct exposure as well as indirect exposure. Direct exposure can occur when the toxic chemicals are inhaled, touched by skin contact, or ingestion of the chemicals. Many of the chemicals found in electronic components can easily leach out into local water sources, find their way in food, and can easily be blown away by the wind and transported into the air. Mercury, a heavy metal found in thermostats, fluorescent bulbs, and other household items bioaccumulates in wildlife, especially fish when mercury is deposited in the lakes and streams. While some fish are safe to eat, others become toxic to the point where little consumption can be very harmful to human health.

Environmental degradation

Performing these informal recycling procedures and disposal methods directly results in environmental degradation and negative ecosystem effects. These toxic chemicals can stay in the environment for very long periods of time and will continue to grow in concentration if the amount of e-waste continues to increase as it is now.

Exposure Routes and Problematic Effects: Electronic waste is hard to dispose of. Electronics are not designed to be taken apart. Most electronics contain hazardous materials that require special handling such as lead, mercury, arsenic, chromium, and cadmium [5]. Despite the risk, many developing countries do not have proper regulations and policies in place to protect the local people and environment. For example, in Nigeria precious metals are removed from circuit boards by using acid, and then dumping them onto the ground or into streams [14]. This lack of regulation puts not only the people handling the waste at risk, but also the environment.

Studies on health effect of e-waste recycling practices have been performed only recently. The effect of e-waste on urinary metabolites [15]. Decreased vaccine antibody titers following exposure to multiple metals and metalloids in e-waste exposed preschool children [11]. Human exposure to halogenated flame retardants (HFR) through dermal adsorption by skin wipe. Dermal absorption would be an important exposure route for HFR [16].

Despite the risks and hazards of handling e-waste, it is a way for locals to make money. The city of Guiyi, in China, employs over 150,000 people. These people lack the proper protective equipment and expose themselves to toxic concentrations of many harmful chemicals [1]. In order to collect the precious metals, other materials are burned or acidically removed in order to expose the more valuable materials. Toxins are released into the environment through disposal processes such as burning, burying, dumping. Three common disposal methods include landfills, melting components, incineration, all of which are capable of contaminating water resources and causing air pollution problems. These toxins can make their way into groundwater creating water pollution problems for nearby plants. The amount of cadmium present in one cell phone battery can pollute up to 600 m³ of water [5]. The toxins exposed to the environment from e-waste disposal threaten local ecosystems. One study in Guiyi tested the surrounding paddy farm soil and found levels of polybrominated diphenyl ethers (PDE) and polychlorinated di-benzo-p-dioxins that exceeded international guidelines for agricultural areas [1]. Heavy metals in the soil can contaminate plants. If these plants are consumed by humans, the heavy metals can then accumulate in human bodies and cause harmful effects.

Studies in Guiyi also found high levels of PDEs, lead, and copper in the towns road dust. Increased dust levels correspond to higher levels of pollution and suspended solids. Dust tested in 2008 in Guiyi found to have lead and copper levels 300 times higher than surrounding areas without e-waste dumping sites. Particulate matter from heavy metals in the air can increase risks of mortality and morbidity. This risk is most serious for workers, as the suspended solids tend to concentrate inside the e-waste dismantling workshop [6].

Human health hazards

There are many human health hazards associated directly with e-waste contamination. Most of the health effects result from different

environmental exposure routes. Additionally, the amount of human health issues increases significantly the closer these people are to informal e-waste recycling areas.

Human Health Effects from Environmental Exposure: The potential human health risks from exposure to e-waste are particularly higher for women and children. Pregnant women and children are the most vulnerable groups but every individual can be affected by the pollutants. This includes not only the workers but all of the residents in the surrounding environment that are being exposed to the spreading environmental contamination [1]. Children are typically directly involved in informal e-waste recycling according to the International Labor Organization and if they are not, they can experience secondhand exposure from toxic e-waste residues that are introduced into their homes from clothing and other materials and objects. This is known as take-home exposure which can lead to long-term low-level exposure, especially considering the hand-to-mouth behavior typical in younger children that can lead to ingestion of toxic substances. These children are considered as valuable workers because they have smaller nimble hands that give them an advantage in dismantling e-waste [5]. Therefore, it is important to address the environmental contamination resulting from informal e-waste recycling and disposal methods because the hazardous chemicals can accumulate within the body. This can potentially cause negative health effects primarily because of the chemicals lipophilicity which is the ability of the chemical to dissolve in the lipids and oils in humans.

A study completed by Tsinghua University in Beijing, China examined the health effects of people in the e-waste recycling communities of Taizhou, Guiyu, and Qingyuan, China. This study revealed that when disregarding the e-waste workers, more than 90% of heavy metal and other pollutant exposure in humans are from dietary intake. Humans can absorb and accumulate toxic pollutants in their tissues. The dietary intake of polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and polychlorinated dibenzodioxins/furans (PCDD/Fs) were measured from the 3 recycling and disposal sites from fish, shellfish, meat, eggs, and more. This study discovered that people living in Guiyu had a dietary intake of over nine times greater than the tolerable dose set by the US EPA. The concentration of PBDEs in breastmilk was also measured for 6-month old infants at the e-waste sites and was determined to be approximately 57 times greater than the tolerable level set by the US EPA. The highest dose recorded was 2240 ng/(day kg bw) which is greater than the US EPA chronic dosage level. PCBs were determined to be 242.61 ng/(day kg bw) from several types of food and water in Taizhou. However, in Guiyu just looking at dietary intake from 7 kinds of fish, the exposure level was 264 ng PCBs/(day kg bw). Newborns in Taizhou appeared to ingest 25 to 100 times the amount of PCBs then the World Health Organization level of toxic equivalent. These infants in Taizhou were also exposed to PCDD/Fs that were 38 to 150 times greater than the reference level set by the World Health Organization [1].

Even though exposure through ingestion of food is the largest exposure route, contaminated air can still negatively impact the environment including wildlife and humans. Children inhale roughly twice as much toxic chemicals in the air compared to adults [5]. In Guiyu, it was estimated that 80% of the children suffer from some type of respiratory disease because of the contaminated air. The World Health Organization states that heavy metals such as lead and cadmium, even at low levels, can threaten child development and cause neurological damage [17]. Workers within e-waste sites have shown to have the most significant concentrations with an average of 1900

ng/day of PCBs which was determined to be 5 times higher than the local residents in Guiyu who are also exposed to high concentrations of contaminants. In the e-waste recycling town of Fengjiang, concentrations of PCDD/Fs in adults were recorded to be 61.11 pg TEQ/kg bw/day and 110.11 pg TEQ/kg bw/day in children which is significantly greater than the World Health Organization tolerable level of 1 to 4 TEQ/kg day [5].

Along with inhalation of hazardous e-waste chemicals, soil and dust exposure routes were also shown to be at significant levels. In Taizhou, children were recorded to have approximately 2.3 pg TEQ/kg bw/day of PCDD/Fs from soil and dust uptake as well as adults with 0.363 pg TEQ/kg bw/day. These values were compared to a control site located in Wenling, China that only exhibited concentrations of 0.0013 and 0.0003 pg TEQ/kg bw/day in children and adults. This means the concentrations of PCDD/Fs in Taizhou were 1200 times greater in regards to soil and dust ingestion. Guiyu reported similar concentrations for children and adults [5].

A study conducted by the Chinese Academy of Sciences and China Institute of Water Resources and Hydro-power Research in Beijing, China, researched the effect of PBBs, PDBEs, and PCBs on the cancer patients living in the e-waste recycling sector. Polyhalogenated aromatic hydrocarbons (PHAHs) include the persistent chemicals of polybrominated biphenyls (PBBs), PBDEs, and PCBs which are toxic and can accumulate in the environment. These chemicals are known to have endocrine disrupting properties and are likely to be carcinogenic. There has been an increasing frequency of cancer including lung and liver cancer that has been occurring within and near e-waste recycling sites. This study concluded that the high cancer incidence in the e-waste recycling and disposal sites may be related to the high concentrations of PBBs, PDBEs, and PCBs that has accumulated in their tissues [7].

The e-waste contamination, particularly from persistent environmental pollutants such as PBDEs, PBBs, PCBs, and PCDD/Fs, needs to be addressed to not only reduce the environmental consequences but also reduce the potential for negative human health effects from the accumulation of these chemicals in human tissues.

E-Waste Mitigation Recommendations

In order to alleviate the environmental and human health effects occurring from informal recycling procedures, developing countries have attempted to use policy. The United Nations Environmental Program created the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal which banned the trading of hazardous waste between nations. Unfortunately, this policy, as well as other policies that developing countries created, was not effective in reducing the amount of informal recycling because there is an overall lack of governance and enforcement resources. The Basel Convention also had many legal loopholes which allowed countries to continue exporting to developing countries under "donation" or "recycling" purposes [1]. Developing countries have tried to invest in and encourage formal facility enterprise infrastructure to mitigate the e-waste problem. For example, China invested in approximately 100 formal facility enterprises within the last 10 years. The formal facilities could not compete with the informal recyclers collection prices. Informal recyclers can offer up to 5 times higher the price that formal facilities can because the formal facilities have to take into account the costs that will be needed to recycle the materials properly [18]. Regardless of legislation and formal

facility infrastructure, the informal recycling sector still recycles the majority of e-waste in developing countries. Therefore, there are several factors that should be taken into account for future e-waste mitigation plans.

First, instead of trying to abolish the informal sector within developing countries, it would be beneficial to take advantage of the large and efficient collection network that the informal sector currently has. For example, in China past experiences have shown that formal facilities cannot compete with the advantages of the informal sector, including their established network, convenience in collection, and their low operating costs. Therefore, future recycling systems should take the informal sector into account. In order to accomplish this, an incentive system, most likely financial, will have to be established in order to make the informal recyclers want to bring their collected e-waste to the formal recycling sector where it can be treated appropriately without the resulting environmental and human health effects. These incentives would also increase the environmental and legislative awareness [18]. The University of the Negev researchers used cathode ray tubes (CRTs) to demonstrate the financial incentive system. The formal recycling facilities would offer a higher price for the CRTs than could be earned by the informal recyclers manually dismantling them. This would provide economic motivation for the informal recyclers to take the collected CRTs to the formal sector to undergo recycling. These concrete incentives encourage a relationship between the informal and formal sectors [19]. Therefore, the formal facilities are using the informal recyclers efficient collection system in a way that reduces the impacts that e-waste has on environmental and human health. Additionally, higher incentives could be proposed for the e-waste devices and components that are the most harmful and problematic. This allows communities to remain informal recyclers but offers them the opportunity to decrease the amount of hazards they are distributing to their surrounding environment from e-waste disposal.

A limitation of this financial incentive plan is that the government would have to provide additional subsidies to the formal facilities in order to start this process. This is primarily because since the formal facilities have been failing, companies are no longer expressing interest in the development of formal recycling enterprises [18]. Therefore, the government has already had to provide subsidies to several of these formal facilities in order for them to remain open. If an incentive system were put in place, the informal recyclers could provide a constant supply of e-waste to the facilities to decrease the current supply deficiency so that the facilities would then be able to become profitable. Therefore, additional policies may have to be implemented to provide economic subsidies for the formal facilities at the early stages of development so that these formal recycling facilities will be able to offer similar prices to what the informal recyclers are currently receiving for their e-waste [4].

Additionally, developing nations need to invest in the resources needed to provide the necessary enforcement and supervision in restricting e-waste importation and the other policies that exist in each respective country. For example, E-waste importation needs to be more effectively restricted, possibly by addition of administrative reforms that will block the legal loopholes that currently exist [4]. The existing and new policies that are put in place within these countries should also address the informal sector more supportively and effectively.

In regards to future mitigation, the manufacturers and producers need to become more involved by creating and implementing take-back systems on their electronic devices. The consumers would then bring their used or broken electronic items back to the manufacturer

where they can be distributed to a facility where the materials will be treated and disposed of properly [1]. Research and development should also be done for these manufacturers and producers to use less hazardous materials in their electronic devices. Additionally, these electronic devices should be created in such a way to make them easier to disassemble and to recycle the reusable materials. Therefore a combination of these factors would result in a more successful mitigation plan for developing countries in the future.

Conclusions and Recommendations

E-waste is being generated at a rapid rate in developing countries around the world. This e-waste recycling issue needs to be addressed to reduce the harmful resulting effects that the toxic chemicals in e-waste have on environmental and human health. The existing policies that developing countries have created so far have not been effective in reducing the amount of informal recycling because there is an overall lack of governance and enforcement resources in these areas. Formal facilities have not been able to compete with the informal recycling. It would be beneficial to take advantage of the existing collection network that the informal recycling sector has in place instead of trying to do the impossible by trying to abolish it. An incentive system will most likely be needed to have the informal recyclers be more willing to bring their collected e-waste to the formal facilities where it will be recycled without resulting in negative impacts to the environment and human health. Additionally, investment in the resources necessary to provide enforcement and supervision for the existing and potential new policies that will be put in place should be implemented. For example, the restriction of e-waste importation needs to be controlled better in order to decrease the amount of e-waste being transported to these informal recycling areas. Considering future mitigation methods, one primary option is for manufacturers and producers to become more involved in implementing take-back systems to recycle their electronic items properly.

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