Environmental and health impacts of informal electronic waste recycling

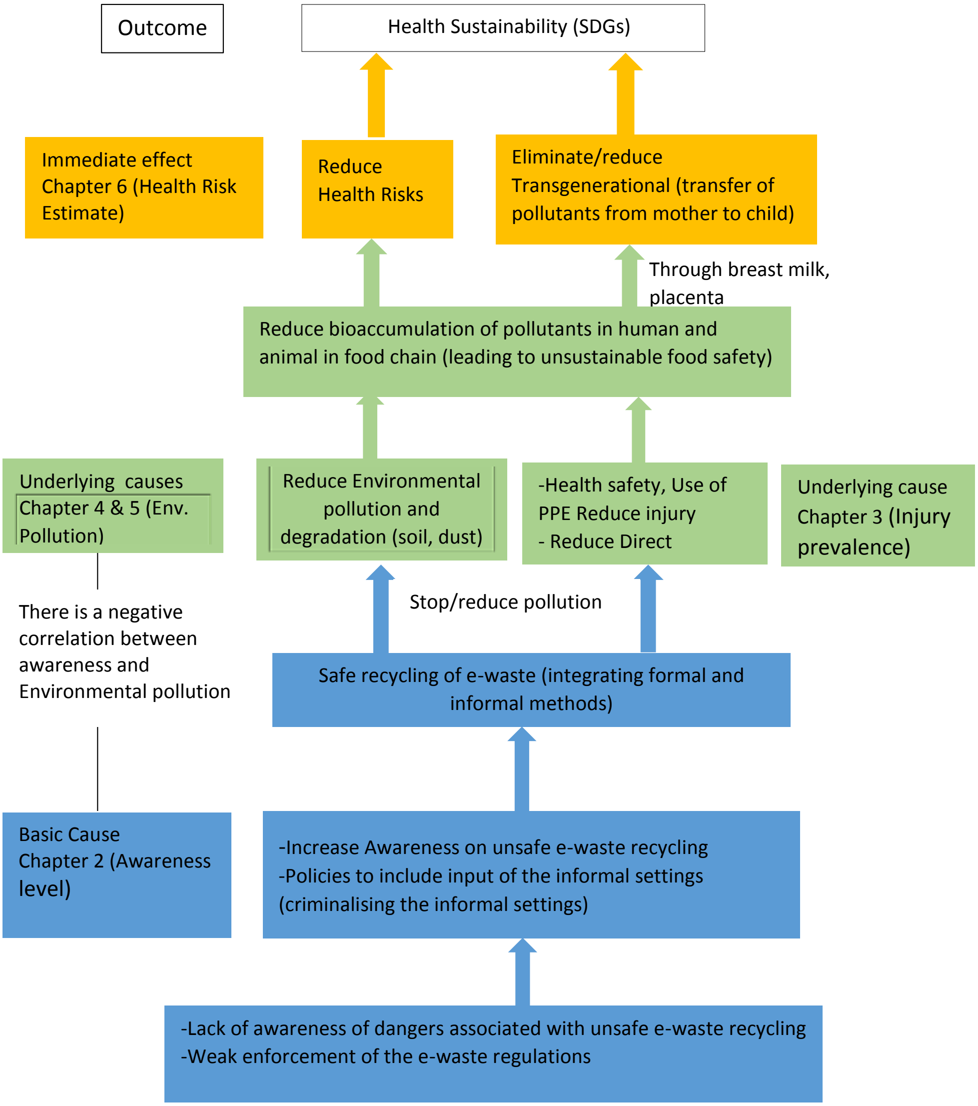
Ohajinwa, C.M.

Author: Ohajinwa, C.M.
Title: Environmental and health impacts of informal electronic waste recycling
Issue Date: 2018-10-23

Chapter 7

General Discussion

Synthesis of the Research Addressing the Impacts of Informal E-waste Recycling



7.Revisiting Research Questions and Findings

7.1 Key Findings

Across the world, electronic or electrical devices have become indispensable in our daily lives, with many people now owning multiple personal electronic devices. This has led to an exponential generation of electronic waste (e-waste) at an annual growth rate of 3–5%, which is approximately three times faster than the growth of other municipal solid waste. In 2016, 44.7 million metric tonnes (Mt) of e-waste was generated globally, and this volume of e-waste is expected to increase by 17% by 2021. Of the volume of e-waste generated, only 20% is collected and recycled formally, the remaining 80% goes undocumented (Baldé *et al*., 2017), and are simply sent to dumpsites/landfills to/in many developing countries where they are recycled informally. Informal e-waste recycling practices release hazardous substances which can have health and environmental consequences (Wong *et al.,* 2007). These practices occur more often in countries (such as Nigeria) where appropriate infrastructure for e-waste management is absent. Considering the attention on the challenges of informal e-waste recycling, there have been several international and national regulations to regulate the sector, but enforcement of these regulations is weak in developing countries.

Despite the draw backs associated with informal e-waste recycling, it creates employment and livelihood opportunities for many families and their dependents. Informal economy thrives in a context of soaring unemployment. This is a major concern in mitigating the impact of informal e-waste recycling without impeding the people's livelihood. Due to the exponential growth of e-waste generated and increasing unemployment, this thesis emphasises on the importance of tackling informal e-waste management from the perspective of providing sustainable solutions. From this perspective, one would want to ask: -

What are the existing management regulations, policies, and guidelines? Are all relevant stakeholders (e.g the e-waste workers) aware of these regulations? How are the regulations implemented? Are the e-waste workers aware of the environmental and health risks associated with informal e-waste recycling? Are the regulations and policies feasible for informal settings? Are there new strategies needed to implement and enforce the regulations and policies more appropriately in the informal settings?

Considering the potential risk of exposure to e-waste mixture chemicals ansd the associated health risks, the focus of this PhD research is on the impact of informal e-waste recycling on the health of e-waste workers and the environment. This study therefore aims to answer the following questions:

- Are e-waste workers in Nigeria aware of health risks inherent in their daily jobs and what factors influence their awareness?

- What is the prevalence and injury pattern among e-waste workers in the informal sector in Nigeria?
- What is the impact of informal electronic waste recycling on metal, concentrations in soils and dusts?
- Polybrominated Diphenyl Ethers (PBDEs) being one of the most harmful substance, what quantity of Polybrominated Diphenyl Ethers (PBDEs) are released into soils and dusts as a result of various activities at informal electronic waste recycling sites?
- Are there adverse health risks associated with exposure to PBDEs and metals at the e-waste sites?

These questions have been addressed in the preceding chapters 2-6. This study conceptualised some underlying causes contributing to informal e-waste recycling and its overall impact on health. The conceptual framework of this research is presented in chapter 1. Each chapter of this research work contributed in addressing the identified causes. The present chapter provides the research synthesis, societal and scientific implications of the findings and recommendations (figure 7.1).

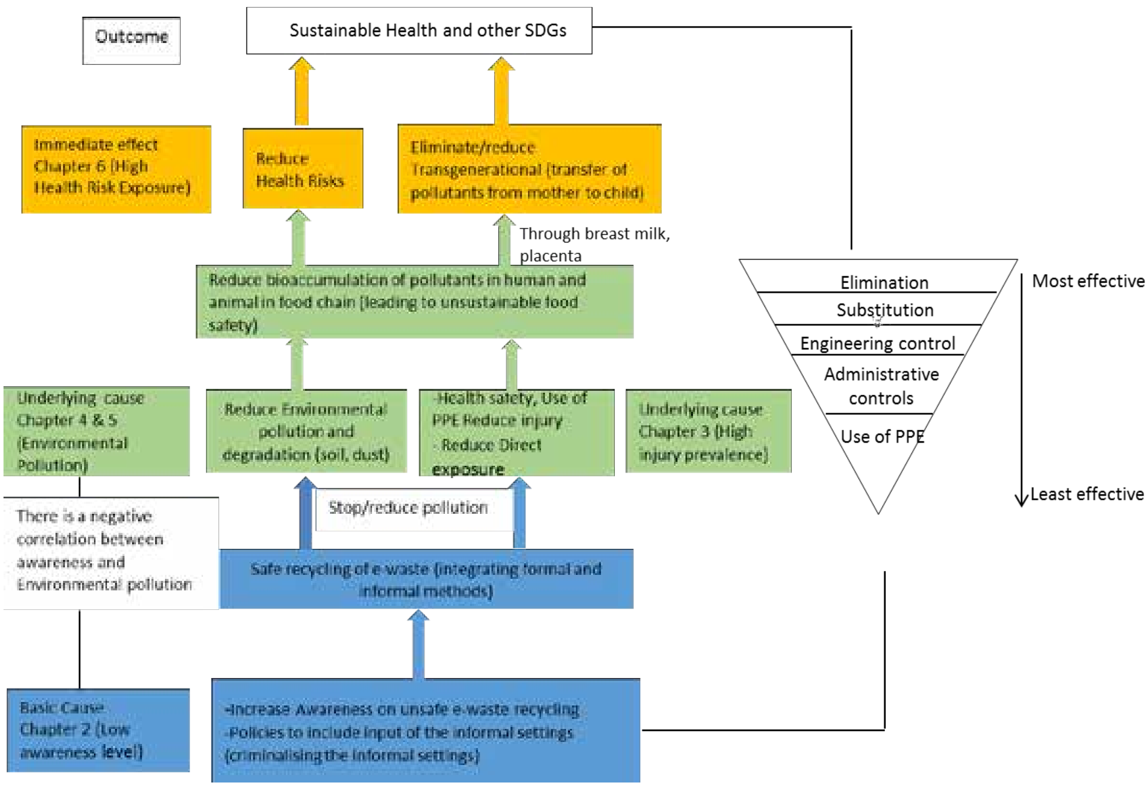


Figure 7.1: Synthesis of the Research showing the Major Outcomes and Recommendations

In addressing some of these questions, the researcher is cognizant of the fact that sustainable development involves human values, such as cultural values, equity, trust, and perceived fair relationship between the formal and the informal institutions. It is important to understand the actual operations of the informal economy, considering that this is a major source of livelihood of the people involved. Therefore the workers (e-waste workers and the control group-butchers) were interviewed. Chapter 2 unveils that the e-waste workers are not aware of the risks they are exposed to daily. The awareness level of the workers shows that informal workers often appear to underestimate or deny the health risks associated with their jobs. This could be because this job is a means of livelihood for them and they cannot escape from the risks easily. This is in accordance with the theory of Cognitive Dissonance proposed by Festinger in 1957 in which he stated that recognition of inconsistency will cause dissonance, and will motivate an individual to resolve the dissonance by either change of beliefs, change of actions, or change of perception of action (Festinger, 1957). They make statements like "*one could get sick from many other things not necessarily due to the unsafe methods of e-waste recycling*" which they practice.

Overall e-waste workers have poorer knowledge (88%), more negative attitude (74%), and more unsafe practices (58%) compared to butchers (control group) regarding the potential health risks inherent to their jobs. The health risk awareness level of the e-waste workers was significantly lower compared with their counterparts (butchers) in the same informal sector, and only 43% of the e-waste workers could mention one or more types of Personal Protective Equipment (PPE) needed for their job compared with 70% of the control group (butchers). The majority (88%) of e-waste workers were unaware that e-waste contains hazardous chemicals which could pose a risk to their health. Seventy percent did not think that the substances they are exposed to at work can pose any health risk and did not think that they could get ill from their jobs, but rather from other sources unrelated to their work or work environment. Some of them said "*one can die as a result of anything, not necessarily this job*". However, none of the groups (e-waste workers and butchers) had remarkable knowledge, attitude or best practice regarding their jobs. This confirms the statements made by Widmer *et al*., (2005), Borthakur & Sinha, (2013) and Lundgren, (2012) who claimed that most of the participants in the informal e-waste recycling sector are not aware of environmental and health risks and do not know of better practices. Only about 4% of the e-waste workers mentioned worrying about their health. The majority (51%) of the e-waste workers and 48% of the butchers reported that their major concern is finance (making more money). This shows that most workers in the informal sector work mainly for economic benefits as also confirmed by ILO (2013).

There was also a correlation between the level of knowledge and work practice. Therefore, increasing the workers' health risk knowledge may decrease risky work practices, as captured in figure 7.1. This suggests that a bottom-up approach in reducing risky practices in the informal sector may be more effective in enforcing the e-waste regulations. To ensure success of any intervention programme in the informal sector, it should be borne in mind that the approach may differ depending on the type of job performed, location, and workers' position in the business, as these were the factors that influenced the workers' awareness level. Determining the level of health risk awareness of the workers was successful despite the drawbacks encountered during the data collection in which the respondents were afraid that their responses might be used against them due to the recent stricter e-waste regulations set by the government.

Chapter 3 presents the prevalence, patterns, and factors associated with occupational injuries among e-waste workers. There was high injury prevalence of 38% and 68% in 1–2 weeks and 6 months preceding the study, respectively. These findings are in line with the findings of a qualitative study in Ghana where the e-waste workers reported high frequency of injuries and no use of PPE (Asampong *et al*., 2015, Akormedi *et al*., 2013). Our study quantified the prevalence of the injuries. Despite the high prevalence of injury, the real proportion of dismantlers that sustained an injury in the timelines studied is expected to be higher than what they actually reported, because most of the dismantlers regarded only deep cuts with blood gushing as injuries, whereas minor and blunt injuries seem normal and are even unnoticed. This observation reveals a gross level of unawareness of the occupational health risks and under-reporting of work-related injuries among informal recyclers as supported by Gutberlet & Baeder (2008). This study therefore recommends an occupational safety and health programme for the informal e-waste sector as captured in figure 7.1. Despite the high occurrence of injury, only 18% of the workers use at least one type of PPE either occasionally or most of the time. The main reasons for not using PPE were 'it is not important', 'discomfort', 'cost' and 'unavailability'. Use of PPE was associated with a higher reported occurrence of injuries. There was also a negative correlation between the number of injuries sustained and the awarenesss level. These findings suggest that use of PPE might have helped to create some awareness/consciousness of potential risks of injuries among those that use PPE, and with the right knowledge, if PPE is used appropriately, injury incidence would be reduced. The main factors associated with incidence of injury were job designation and the geographical location.

To understand if the workers are at any health risk because of chemical exposure, environmental samples were collected and analysed for chemicals present in electronics. In Chapters 4 and 5, the environmental impact of various informal e-waste recycling activities (burning, dismantling and repair) was examined in top soil and various dust samples (floor dust, roadside dust, and direct dust from inside and outside the electronics). Electronic and electrical equipment contains over 1000 different substances, some of which are hazardous elements such as lead, mercury, cadmium, arsenic, beryllium and persistent organic pollutants (including polychlorinated biphenyls and brominated flame retardants) (UNEP-DTIE, 2007). These mixtures of different substances include both chemicals present in EEE components and mixtures of chemicals released into the environment during e-waste combustion, dismantling and/or repair. These chemicals may pose significant threats to the environment and to human health given the fact that these substances persist in the environment and have a great potential to accumulate in human and animal tissue (Brigden *et al*., 2008; Asante *et al*., 2012). In the environment, soil and dust are the main receptors of direct and air-borne emissions from informal e-waste recycling. Therefore, they are the most important environmental media that can reveal the distribution and fate of contaminants present in the terrestrial environment (Leung *et al*., 2008, Ackah, 2017; Tang *et al*., 2016, Tang *et al*. 2013, Xu *et al*., 2015; Lu *et al*., 2014; Wuana & Okieimen, 2011; Banerjee, 2003).

In Chapter 4, metal concentrations (inorganic chemicals) at e-waste recycling sites (burning, dismantling, and repair) were compared to the concentrations at control sites in three study locations in Nigeria (Lagos, Ibadan, and Aba). In the three study locations, mean metal concentrations at the e-waste recycling sites exceeded the concentrations at the control sites and the Nigerian standard guideline values by factors of 100s to 1000s. Burning sites contained the highest pollution level, followed by dismantling sites, then repair sites (see figure 4.3). Our findings show that informal e-waste recycling is a major source of metal pollution in Nigeria, as captured in figure 7.1. The metal concentrations found were also higher than levels reported in earlier studies at the same locations in Nigeria, indicating that the situation is worsening. There was a negative correlation between awareness and metal concentrations at the sites, indicating that as the workers' knowledge increase, the metal pollution decreases.

Polybrominated Diphenyl Ethers (PBDEs) do not occur naturally in the environment, but traces of PBDEs were found in control sites, indicating deposits of PBDEs in places away from e-waste recycling sites (source of pollution). PBDEs are highly persistent in the environment, bioaccumulate in food chains and have a high potential for long-range environmental transport. These chemicals have been detected in humans and in increasing concentrations in various environmental matrixes. There are evidences of harmful effects in humans and wildlife, which include endocrine disruption, immunotoxicity, reproductive toxicity, effects on fetal/child development (ATSDR, 2004, Zhang *et al*., 2016, Berg *et al*., 2013, Kristen *et al*., 2013), thyroid and neurologic function (Koibuchi & Yen, 2016), and cancer (Darnerud *et al*., 2001). Due to the environmental and health concerns, PBDE have been banned in the European Union, they are voluntarily phased out in the USA since 2004 (Betts, 2008, La Guardia *et al*., 2006, EU, 2017), and are listed as POPs by the Stockholm Convention (UNEP, 2009).

PBDEs have been classified as a possible human carcinogen by the US EPA since 2004. Seventeen PBDE congeners were measured in the top soil and dust samples, as reported in chapter 5. The same pattern emerged as compared to the metal concentrations. This study showed that PBDE concentrations at the e-waste recycling sites were elevated compared to the concentrations detected at the control sites by multiple folds (figure 5.3). We found high concentrations of PBDE congeners present in electronics at the e-waste sites, with the higher molecular weight PBDEs (BDE-209, BDE-153, BDE-183) having the highest concentrations, and BDE-209 being the most abundant. The general pattern of the total PBDE ($\sum_{17}$PBDEs) distribution at the *e*-waste sites showed concentrations in this decreasing order: burning sites > dismantling sites > repair sites > control sites. This shows that burning activities contribute most to the PBDE concentrations in the environmental matrices. There was a significant difference in concentration of PBDEs among the different *e*-waste activities. This finding confirms that the type of activities at the sites influences the level of PBDEs at the sites. This study demonstrates again that crude recycling of e-waste is a significant contributor of organic pollutants in the environment, this is also shown in figure 7.1. In addition, there was a negative correlation between awareness and metal concentrations at the sites, suggesting that increasing workers' knowledge and awareness may decrease metal pollution from informal e-waste recycling.

Due to the work practices of the e-waste workers and the high concentrations of e-waste chemicals (metals and PBDEs) found at the e-waste sites, the potential health risk for the e-waste workers was estimated. Risk assessment is the process of quantitatively determining the likelihood of adverse effect resulting from exposure to hazardous substance, and the probable magnitude of adverse health effects over a specified time period. Exposure to PBDEs and metals was considered as a proxy for exposure to the complex mixture of organic and inorganic chemicals respectively as present at the e-waste recycling sites. E-waste workers are inadvertently exposed to both classes of chemicals at various informal e-waste recycling sites. In Chapter 6, the estimation of health risks due to exposure to mixture of PBDEs ($\sum_{17}$PBDE) and metals was based on the quantification of the risk level and was expressed in terms of either a cancer risk or non-cancer health effects. The estimations are commonly reported as average daily dose (ADD). Exposure to chemicals can occur via three main pathways: (a) direct inhalation of vapour or atmospheric particulates through mouth and nose; (b) dermal absorption of PBDEs in particles adhered to exposed skin; and (c) ingestion of atmospheric particulates due to their deposition/mistaken ingestion (Ferreira-Baptista and Miguel, 2005). Overall, the cumulative hazard index (PBDEs and metals) exceeded the acceptable (safe) limit for non-cancer effects and cancer risks for all exposure routes, in all locations and at all sites, with the burning sites having the highest risks . Dermal contact is the dominant route of exposure, followed by ingestion, while exposure via inhalation is negligible. This indicated that e-waste workers and other people at the e-waste sites are prone to adverse health effects. It is strongly recommend employing hierarchical control methods in the management of informal e-waste recycling without impeding livelihood. This is simplified on the conceptual frame work diagram (figure 1.1) and the synthesis on figure 7.1.

7.2 Scientific Implications

This study employed epidemiological methods of sample selection to ensure that the target groups and sites are rightly selected, adequately represented and described. Therefore, the health and environmental implications of informal e-waste recycling revealed and the recommendations in this study are applicable to similar situations in other places where of informal e-waste recycling is practiced. This study estimated the health risks the workers are exposed to, the findings are worrisome and cannot be ignored, pollution levels are high, as the e-waste workers are exposed to high health risks, and they workers are unaware of the health risks associated with their jobs. There is a need to perform additional biomonitoring studies (using blood, urine, breast milk samples) of the e-waste workers and even air sampling at the informal e-waste recycling sites, and this attention should be extended to children in the e-waste recycling vicinity. However, greater knowledge is gained if epidemiological studies are linked to the findings from toxicological studies. Toxicological models which have served as a valuable tool for analysing experimentally generated toxicity data, for predicting adverse effects in humans, and for estimating upper and lower bounds on health risks. Combining epidemiological and toxicological studies gives a more realistic description of cause and effect of the toxicants to humans. I recommend further toxicological and genetic studies to determine the real health effects even at molecular level associated with exposure to multiple chemicals through different exposure pathways which might not have been identified in this study. I also recognize that I did not identify all compounds present in the emissions at the e-waste recycling sites. There is a need for further epidemiological studies on health of the e-waste workers, other workers and residents around the e-waste sites. Furthermore, further epidemiological-toxicological studies in this area are recommended to be carried out to ensure that important associations are identified, associations are not overemphasied, and more serious health risks are not missed. In addition, it is highly likely that the evidence gained from these combined studies drive will public policies and in turn will lower exposure to health risks. It is important to note that exposure to these chemicals could be transgenerational, therefore urgent measures should be in place to mitigate exposure to these hazardous chemicals as shown in figure 7.1.

7.3 Recommendations

The findings of this study are a wake-up call on the urgent need for safety measures to be enforced in the informal e-waste recycling sector in Nigeria, and our result can be related to similar situations anywhere globally. The low health risk awarenes level, low use of PPE, high prevalence of injury among the e-waste workers, high concentrations of metal and PBDEs in the environment, and high risk of adverse health effects, give an insight into the magnitude of future environmental and health problems of uncontrolled informal e-waste recycling to both the e-waste workers and those around the e-waste sites. This also means that the impact could go beyond the present to future generations (unborn children) that are likely to inherit the health problems if appropritate actions are not taken now. The recommendations that are derived on the basis of the key outcomes of this thesis are the following:

- There is a need to implement an end-of-life product framework which is operational in developed countries such as a product take-back system and extended producer responsibility (EPR) schemes. This will reduce the quantities of e-waste informally recycled.
- There is a need to eliminate/ban risky practices such as open burning and dismantling that directly emit hazardous chemicals and cause noise pollution.
- There is a need to substitute risky practices such as burning with safer alternatives such as striping of copper wires instead of burning them, use of machines to dismantle the devices instead of manually hitting and dismantling them which consequently releases hazardous substances and causes noise pollution.
- The remains of the e-waste parts after extraction of valuable materials should be sent to landfills, instead of dumpsites.
- The primary approach to address the problems in informal e-waste sector has been command-and-control regulations that ban international trade in used electronics and e-waste and outlawing informal recycling, which punishes informal recyclers through fines and other measures. However, a major concerns about these regulations is the effectiveness of such command-and-control regulations even in countries that are more developed than Nigeria? Given the social and institutional constraints which led to weak enforcement of command-and-control policies to address informal recycling, there is a need to devise better more suited approaches to implement existing e-waste regulations. Formal institutions such as the National Environmental Standards and Regulations Enforcement Agency (NESREA) should appreciate, understand and collaborate with the informal associations.
- Given the hostility that the informal sector has faced in the past, establishment of trust might be challenging. The enforcement agencies must not be seen to be antagonistic so as to

influence the workers in the informal sector to align with government policies. Although the informal associations are self-organizing, they can be encouraged to abide by government regulations if they perceive that they are appreciated by the enforcement agencies (National Environmetal Standards and Regulations Agency (NESREA) IN Nigeria. NESREA and the Ministry of Health can work together with the informal associations to develop effective grassroot communication methods which will improve the workers' health risk awareness. Solutions for effective enforcement of e-waste regulations are most likely to work when the workers generate the solutions themselves.

- Since the level of knowledge correlated with work practice and high exposure rate, there is a need for an urgent occupational safety and health programme suitable for the informal sector to be developed and implemented.
- The current policies -if successfully enforced- would reduce the environmental and health impacts. However, in low income countries with high formal unemployment rates, the current policies have negative trade-offs on:- the economic benefits, access to affordable used electronics, and encourages disposal of electronic devices at minor damages instead of reuse. In addition, the informal sector is extremely effective at collection, repair, reselling and dismantling electronics in developing countries.

Following these major concerns, we recommend integrating the best of informal and formal recycling methods important to mitigate environmental damages while sustaining the social benefits and the livelihood that e-waste recycling provides in developing countries. This includes: (1) Mixing the informal and formal e-waste recycling processes as already recommended by wang *et al*. (2013) and Manhart *et al.* (2011) who observed that mixed systems are sustainable, and (2) formulating and enforcing policies and regulations with inputs and considerations from the informal sector. It is important to explore alternative e-waste management strategies that are appropriate for the informal sector while preserving social and economic benefits. Sustainable improvement in the e-waste recycling sector is possible, but it also depends on the social reputation of the enforcement agences in the sector across ethinicity, business, and the willingness of enforcement agencies to appreciate and work with the all the e-waste workers in the informal e-waste recycling sector.

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