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An Overview of Informal WEEE Management in MTN Phone Village, Rumukurushi, Port Harcourt, Nigeria

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Abstract

In developing nations, the informal sector is frequently used for the management of Waste Electrical and Electronic Equipment (WEEE), which presents serious threats to human health and the environment. This study carried out an overview of the informal WEEE management system adopted in MTN Phone Village in Rumukurushi, Port Harcourt, Nigeria, the associated problems, and measures to address the problems. This study highlights several issues by investigating how WEEE is currently collected, stored, disassembled, sorted, recycled, and disposed of. These issues include serious health concerns for workers, environmental contamination, financial limitations, and regulatory inadequacies. The results emphasise the necessity for more awareness, better infrastructure, stronger regulations, and financial incentives to transition informal recyclers into the formal economy. The study proposed the restriction of the activities of informal recyclers to WEEE collection only, coupled with the application of the Just-in-time lean management principles. By tackling these problems, the study hopes to provide long-term solutions that lessen the negative effects of informal WEEE disposal, eventually safeguarding the environment and public health. The outcomes of the study identified a research gap in the field. It also contributes to the existing knowledge in the field of specialisation. Furthermore, the study recommended, restricting the activities of informal recyclers to WEEE collection coupled with the adoption of the Just-in-time (JIT) lean management principles to the current WEEE management system in the location and other areas faced with similar challenges.

Subject Areas

Waste Management

Keywords

Waste, WEEE Management, Informal, Environment

1. Introduction

Electronic and electrical equipment that has been discarded is referred to as Waste Electrical and Electronic Equipment (WEEE) or e-waste. The informal sector handles the majority of e-waste management in several developing nations [1]. This method of WEEE management frequently lacks regulatory oversight resulting in severe health and environmental risks [2] [3]. One prominent location for these informal WEEE management activities is the MTN Phone Village in Rumukurushi, Port Harcourt, Nigeria [4]. Tackling the challenges associated with informal WEEE management due to the uncontrolled activities of informal recyclers is all that is required to prevent pollution such as land, air, and water, as well as environmental pollution in the selected research location [5]. Informal WEEE management poses serious risks to human health, the environment, and the local economy [6].

Port Harcourt, an oil city in Nigeria, usually experiences a massive number of individuals entering the location in search of financial benefits from the oil and gas industries. Because of this ever-rising number of inhabitants, there is an increase in the population, WEEE, consumption of materials, and other environmental contaminants. The quantity of WEEE that emerges from these devices when they are no longer useful has been on a steady increase [7]. Furthermore, according to the same study, this is largely a result of the increasing need for communication and information technology, enhanced technology in some parts of the world, resulting in the dumping of "old and discarded" electronic and electrical equipment to countries like Nigeria where such items are still gaining patronage. Those items usually expire or are close to expiration before they are transported into poor nations, which tends to increase the quantity of generated WEEE.

According to Kalamaras *et al.* [8], WEEE, which appears to be among the biggest and ever-rising streams of waste globally has become an issue of serious concern due to its associated challenges. The problem created by WEEE appears to be twofold. First and foremost, it is among the most speedily increasing waste streams globally, standing as a potential threat to humans, animals, and the environment. Secondly, as a result of its makeup, which is complex, WEEE is also one of the most difficult waste streams to manage [9]. In Port Harcourt, a city in the south-south geopolitical zone of Nigeria, the WEEE collectors do not practice formal recycling methods. The system in practice is the informal recycling method carried out majorly at the dumpsite where they engage in the sorting of WEEE as well as recycling [10].

Ohajinwa *et al.* [11], put forward that the informal recyclers engage in several activities, which include the recycling of WEEE. Their services are usually at a low cost but the working procedure used is not safe, hence their health is at risk. In a related study by Amadi and Chijioke [10], the WEEE and other waste are usually gathered at Igwuruta, Elelenwo, and Abuloma locations in Port Harcourt unsorted. WEEE serves as a source of raw materials but during the informal recycling process, the estimated useful metals recovered is only 25 percent [12] [13].

WEEE, in a study by Mihai *et al.* [14], appears to be a growing waste stream worldwide. The inappropriate handling of WEEE creates room for serious pollution and health-related challenges. This is usually the case as the dismantling of WEEE is carried out under "poor conditions". Dumping of WEEE in Africa has been an age-long practice. It is usually carried out by uneducated individuals and this exposes them to harmful substances. Due to lack of organized collection centres in Nigeria, WEEE is dumped together with waste from the hospital as well as others from the community and in the process creates more complications in the sector. In some communities, WEEE is dumped inside bodies of water and open fields resulting in environmental pollution. Items considered to be of no use economically are usually burnt regularly to reduce their quantity or deposited in open fields or water bodies. Indiscriminate discarding of WEEE has resulted in the increase in polybrominated diphenyl ethers and polychlorinated biphenyls concentration in the serums of individuals in the location. Fluorinated biphenyls and analogues are also toxic pollutants emitted due to indiscriminate dumping of WEEE [15]-[20].

Electronic appliances such as televisions, monitors, etc., are designed to make life simpler and happier for us, but they contain harmful elements that are evident during disposal or recycling. The majority of those who make use of them are not aware of the associated risks of using them frequently [21]. The landfills, as well as unauthorised dumping sites, appear to be the terminal point of the majority of the WEEE gathered [22]. Harmful gases are usually released into the environment during the burning of WEEE [18] [23]. The disposal and recycling of cathode ray tubes and CRT have the potential to expose life to health risks due to the presence of lead and antimony. The presence of a high percentage of lead in CRT funnel glass (*i.e.* 22%) makes it harmful to life. Besides, lead, CRTs consist of fluorescent powders, barium, and cadmium, all of which are toxic. The harmful elements contained in CRTs are easily absorbed in the soil with time and are consequently passed to humans and animals [24]-[27].

The presence of devices that contain mercury causes soil pollution as well as health risks. Both non-beneficial and non-essential components of mercury are potential risks to living things globally. The presence of mercury contamination in the environment can result in food chain pollution especially when it accumulates in edible parts of plants. Mercury appears to be more poisonous than lead and cadmium and it causes loss of hearing, vision, and mental retardation [28]-[30]. WEEE comprises toxic elements as well as metals and as such constitutes a serious threat to health. The adjectives commonly used to describe WEEE processes are hazardous, toxic, and dangerous, as such a lot of attention is required to help proffer a solution to this environmental challenge. The tissue and surface of edible fresh vegetables easily harbour heavy metals. This exposes human life to poisonous substances. Skin contact and drinking water have also been recognised as means of exposure to metals that are toxic [31]-[33].

Unprofessional WEEE burning and dismantling methods significantly contribute to the pollution of air. This can result in secondary exposure as some of the pollutants are able to travel over a long distance to other locations from the recycling sites [34]. The soil, as well as the crops grown in the WEEE dumpsites, are usually faced with a high concentration of metals such as lead, zinc, copper, etc. Accumulation and update by plants constitute the major entry channel for metals that are toxic to animal and human food. Examples of such toxic metals are metalloids such as lead, mercury, cadmium, selenium, and arsenic. Crops that grow in the metal-polluted location usually show a reduction in growth, reduced biomass production, accumulation of metal, and alteration in metabolism. A lot of individuals like to grow crops around and within the WEEE dumpsite, as they believe the land is fertile and as such, crops will grow well. Research has demonstrated that locations contain a lot of metals [35]-[38].

In recent research by George, Mapa, and Dinggai [39], the increasing quantity of WEEE is ascribed to several factors, and these are a result of technological improvement, availability of assorted electronic and electrical devices for sales, reduction in prices of electronic and electrical devices, and the extreme "high demand" for them. WEEE serves as a good source of rare metals, plastics, etc. This is a result of the continuous need for metals, reducing mineral resources, natural resources exploitation as well as the environmental and cost implications of mining. Several methods are adopted to extract metals, for example, studies have shown that copper present in Printed circuit boards (PCB) can be extracted with the use of a mixture of aqueous acid and supercritical CO_2. Studies have also shown that rare earth elements can be recovered via electrochemical recovery. In a recent study, important metals, for instance, copper, silver, and gold were recovered from the printed circuit board of computers that are no longer in use via physical separation after which, the leaching technique is applied. In addition, copper can be directly separated and recovered for waste PCBs via slurry electrolysis carried out with an acidic system. Product designs that are environmentally friendly have been encouraged in the European Union via the legislature to support the recovery of valuable materials from WEEE [40]-[46].

In Cole *et al.* [47], "the recovery and treatment of WEEE" serve as an alternative source of important elements, for example, copper, gold, etc. The indiscriminate WEEE disposal and the challenges that come with the inappropriate disassembling and management of WEEE are observed in numerous countries that are still developing, resulting in numerous consequences [48]. An effort made by Khan *et al.* [49], indicates that most of the WEEE that is globally generated yearly, which amounts to at least 40 million tonnes finds its way to developing countries as their dumping ground. Nigeria now appears as one of the dumpsites for Asia, the US, and Europe WEEE [50]. Ferronato and Torretta [48], put forward that, the developed countries have seen the export of WEEE to Asia and Africa as a preferred option, instead of using the prospect to develop their national recycling infrastructure, develop an innovative design that stops the existence of further toxic material use and switching to cleaner sustainable technologies.

In Adeola [51], it was observed that the amount of WEEE generated worldwide amounted to about "50 million metric tonnes" in 2018. In his work, he emphasized that WEEE production is one of the consequences of the manufacture and usage of electronic devices. Furthermore, the research work indicates that the multipurpose nature of the majority of information and communication technologies (ICTs) has made them desirable to consumers and as a result of their comparatively short life, there has been a build-up of great capacity of WEEE, which constitutes problems at all levels. WEEE contains hazardous elements and this poses problems to the government in terms of its management [52]. This calls for concern as such, it has attracted a lot of awareness lately due to its uses and effect on the environment [53]. The estimated quantity of WEEE produced worldwide in 2018 increased to 49.8 metric tons [51].

The purpose of the study is to explore informal WEEE management system adopted in MTN Phone Village in Rumukurushi, Port Harcourt, Nigeria, the associated problems, and measures to address the problems.

Advantages of WEEE Management System

There are several benefits associated with Waste Electrical and Electronic Equipment (WEEE) Management system, especially when it comes to resource conservation, economic gains, and environmental sustainability [54]. Among the key advantages are:

- Hazardous substances including lead, mercury, and cadmium are frequently found in WEEE. By managing them properly, these materials are prevented from contaminating air, water, and soil [55].
- Effective WEEE management minimises the amount of waste moved to landfills, which reduces environmental pollution and saves landfill space [56]-[58].
- WEEE comprises valuable metals such as copper, silver, and gold, silver, as well as, recyclable materials like glass and plastics. Recycling these items decreases the demand to obtain virgin resources [59]-[61].
- Recycling metals as well as other materials from WEEE requires less energy than creating them out of raw materials, this contributes to energy conservation [62]-[64].
- Industries involved in WEEE management create jobs through refurbishing activities, recycling, sorting, and collection [65]-[67].
- WEEE management enables businesses to remain compliant with environmental regulations, abstaining from potential penalties and legal complications [68].
- Companies that show dedication to WEEE management can improve their

brand reputation and attract environmentally sensitive customers [69].

- Refurbishing and reusing electronic equipment prolong its life cycle, this helps to promote a circular economy in which resources are utilised more efficiently [70] [71].
- The demand for more convenient recycling and disposal motivates producers to create environmentally friendly goods [72].
- Proper WEEE handling decreases the danger of hazardous exposure for recycling personnel and the general public [73].

2. Methodology of the Literature Review

The study literature review was carried out using databases that are web-based such as Scopus, Google Scholar and General, Web of Science, and Mendeley. The main database used in the study is Google Scholar. The literature review was done with the help of search strings such as "informal recyclers" and "WEEE management" or "e-waste management" alongside different keywords. Keywords that relate to WEEE management or e-waste management were considered during the literature search. The keywords are recycling, dismantling, hazards, environmental pollution, risk assessment, reuse, sorting, landfills, dumpsite, land pollution, metal recovery, extended producer responsibility, etc. Five thousand four hundred and forty-five (545) data materials were returned during the search on the Google Scholar database but due to factors such as the abstract and title of papers published from the study, coupled with the fact that repeated pieces of information were removed. The data size was reduced to about 500 data materials. The study considered both criteria for inclusion and exclusion. The criteria for inclusion and exclusion are given below.

2.1. Inclusion Criteria

- Include peer-reviewed journal articles, conference proceedings, dissertations, and reports written in English.
- To ensure the literature is up to date, the study included research published within the last five years.
- Include empirical studies such as randomized controlled trials (RCTs), observational studies (cohort, case-control, cross-sectional), qualitative studies, and systematic reviews/meta-analyses that investigate the topic of interest.
- Include studies with persons 18 years and above who have a documented medical condition or risk factor related to the study research questions.
- Include studies that evaluate the impact of a specific intervention, exposure, treatment, or risk factor relevant to the study research questions.
- Include studies that assess important outcomes such as clinical outcomes (e.g., morbidity, and mortality), patient-reported outcomes (e.g., satisfaction, and quality of life), or intermediate outcomes (e.g., physiological measures, and biomarkers).
- Include research done in any geographical region to ensure an accurate repre-

sentation of the literature.
- Include research undertaken in a variety of contexts, such as academic institutions, clinics, hospitals, and community settings.
- Include studies that have appropriate methodological quality, as determined by validated quality assessment methods or criteria relevant to the study design.

2.2. Exclusion Criteria

- Exclude commentaries, editorials, opinion pieces, letters, and non-peer-reviewed publications.
- Exclude papers published more than five years ago to prioritise recent works of literature and ensure relevance with current practice.
- Excludes studies published in languages other than English owing to proficiency constraints.
- Excludes non-empirical studies, such as letters to the editor, commentaries, narrative reviews, and editorials.
- Exclude studies on pediatric populations or particular subgroups that are not relevant to the study research questions.
- Exclude studies that do not include any specific intervention, exposure, treatment, or risk factor of interest.
- Exclude studies that do not measure outcomes relevant to the study research questions or report outcomes of interest.
- Exclude studies done in geographical areas that are unrelated to the research scope or context.
- Exclude studies done in settings unrelated to the research questions or population of interest.

3. Results

3.1. WEEE Category

The record indicates that 40 - 70 million tons of WEEE are generated in the world annually, which is seen as a 3 percent increase [74]. Electrical and Electronic equipment close to the EoL period is creating a global problem, particularly in many developing countries of the world. WEEE continues to rise more than expected due to the manufacture of new EE devices, which makes the initial product obsolete [75] [76]. In China, obsolete PCs and TVs are at an increasing rate of 24.69% and 8.2% annually [77]. In India, WEEE annual generation was estimated to grow at 7% as recorded by [78]. In most European countries, a disturbing growth rate was also recorded where 5 - 7 million tons are produced on a yearly basis [79].

The growth of WEEE in every five years' time in European countries is increasing at the rate of 17% - 27%, amounting to three times the average municipal growth rate of WEEE generated yearly [49]. In North and South America, the number of outdated EEE products stored or discarded as waste is growing at an alarming rate. In the continent, out of the millions of WEEE generated, only a few percent were recycled and landfilled, and some were transported to developing nations [80]. In Europe, the annual volume of WEEE generated by households is estimated to be approximately 7 million tons/year [81]. WEEE stream globally may change drastically if disposal to landfill and incineration in North America is reduced and exports for reuse to developing nations increase.

More Studies have indicated a large number of 400 - 700 million units of outdated PCs in developing countries by 2030, as being compared with developed nations of 200 - 300 million [82]. Household WEEE generation exceeded an annual amount of 20 million tons in 2005, as recorded with the exclusion of Canada and North American nations. In 2005, a total amount of 3.8 million tons, totalling about 20% of the world WEEE stream was shipped to developing countries with landfilling as the option [81]. Basel Action Network reports millions of used computers at the end of life period are transported into Asian and African countries from the US, and Europe adding to the WEEE generation and increasing the rate of WEEE disposal in developing nations. The ten categories of WEEE as in Gap [83] as shown in **Figure 1**.

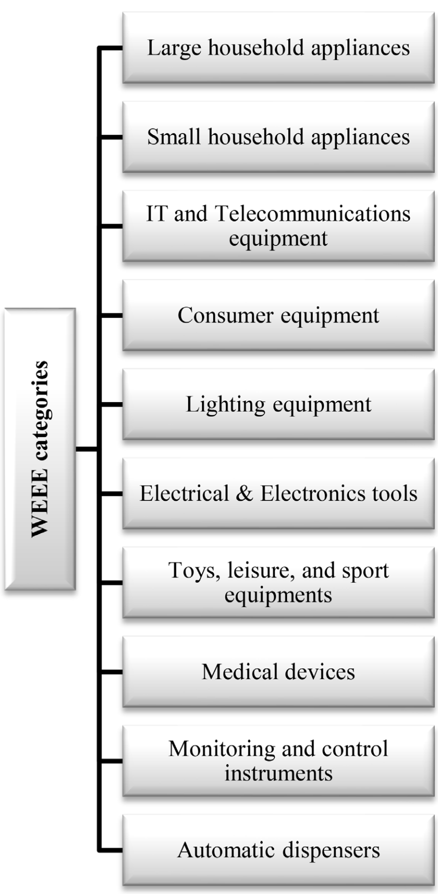

Figure 1. The 10 WEEE categories.

Details of the devices in the ten WEEE categories as in WEEE [84] are given in **Table 1**.

Table 1. 10 categories covered by the WEEE directive.

S/no	WEEE category	
1	Large household appliances	air conditioning unit, if within a household or business system (units built into non-EEE, such as a lorry or boat are exempt), if the unit contains substances used for refrigeration report as category 12; air curtains; air filtering and extracting systems, electrically powered filters, fan systems and extractors, including those built into or attached to a building, if the unit is built into non-EEE such as a lorry or boat, it's exempt cooker hood furniture that needs electricity to work properly, such as office furniture, for example a desk with speakers, display screen or integrated smart features, does not include electrical upholstered domestic seating (see Non-EEE product examples). Report electrical items that are plug and play or retrofit separately (see also category 8) gas boiler, where they rely on electricity to work properly gas cooker, if it will work as a gas cooker without electricity, such as one with a clock or igniter powered by electricity, it's not an EEE product, if it needs electricity to work properly, for example to control the burners, it's an EEE product spa baths, hydrotherapy baths and computerised massage baths sunbeds, report fluorescent bulbs under category 13 stairlifts under floor heating systems powered by electricity water coolers (bottle or mains supply), if it contains refrigerants, report under category 12
2	Small household appliances	air fresheners and perfume sprayers, includes plug-in or battery powered; extension cords, multi-terminals, adaptors and extension leads, if sold as part of a specific product, report under the product's category; electric ironing board, with specific electronic functionality electric shower, electric pumps and control units supplied as part of a shower package are EEE products; loft ladders with electronic controls; massage appliances, for example massage pads that fit onto chairs; roller screens with electronic winders; sockets, switches, dimmers and plugs; taps with extra functions, such as sensors or safety features; torches and bike lights, includes filament bulbs and LED torches; travel adaptors which enable any UK electrical appliance to be plugged into an electrical socket in another country
3	IT and telecommunications equipment	car diagnostic equipment, equipment plugged into a car's central processing unit to diagnose and record faults; cards with chips, for example, set top box cards and cards that need electronic or electromagnetic fields to work, such as pre-paid Oyster and travel cards (not bank cards); HDMI cables; memory cards, USB sticks and SIM cards; power packs and power banks, rechargeable power banks or single use batteries that provide a portable power supply for electronic devices, used to recharge mobile smart phones or tablets when mains power is unavailable (deduct the weight of the internal battery from the overall weight of the power bank unit); printer cartridges that need electric currents or electromagnetic fields to work, exclude the ink from the weight you report; radio frequency identification devices (RFID), includes radio tracking devices, anti-theft devices and electronic tags for criminals (a RFID security feature that forms part of the product's packaging is not an EEE product); satellite navigation (sat nav) systems, sat navs are EEE products, those permanently wired and fixed into a vehicle or yacht are part of the vehicle and are not EEE products; smart mirrors with integral displays and WiFi or bluetooth technology; touch screens that have integral computers, such as e-readers, tablet computers and patient check-in systems; USB memory sticks and drives
4	Consumer equipment	aerials, antennas and digital TV dishes; baby monitors; in car entertainment, units that are not permanently installed in the car are EEE products, units purchased separately and permanently wired into the car, and will remain so until sold or scrapped, are not EEE products; security systems including CCTV with motion sensors, video or stills camera and display equipment integrated into the system (classed as equipment for recording or reproducing sound or images), individual items not integral to the system may need to be reported in a different category, such as a display monitor in category 11; set top boxes; single-use cameras, classify as B2B, they're usually returned to a film processor for recycling or disposal

Continued

5	Lighting equipment	ceiling rose with flex and lamp holder; decorative lighting chains and other decorative luminaires; household luminaires, including table, wall, ceiling, garden and other light fittings, include lampshades when sold with the luminaire; illuminated emergency exit signs; luminaires with movement detectors; mirror with integral lamps and light fittings, for example theatre mirrors; street lights, where parts are put on the market separately only the lantern, wiring and control box are EEE products, not the concrete or steel posts, report the lamp in category 13; trailer light boards, detachable lights for caravans and trailers
6	Electrical and electronic tools (except large scale stationary industrial tools)	electric fences; pumps, filters and fountains for garden ponds, pumps that rely on electricity to function; wind turbines, small scale use such as by a householder, on a smallholding or at the roadside, large scale wind turbines are exempt (they are fixed installations)
7	Toys, leisure and sports equipment	clothing where it includes a fundamental feature which needs electricity to function, such as a gym top with a heart rate monitor, heated walking jacket or a hat with integral speakers; e-cigarettes; electric bicycles, these are not covered under the "means of transport for persons or goods" exclusion unless they are "type approved", for details see European Commission guidance; fish tanks, report the whole weight of a tank with a light, heater or pump supplied as a single unit; games consoles, report in this category even if they have extra functions like a DVD player; gym equipment, report the whole weight of the product
8	Medical devices (except implanted and infected products)	blood glucose meters or testers; furniture designed to help mobility, such as hospital beds and riser chairs with movement controls that need electricity to function; hearing aids; x-ray machines used in hospitals
9	monitoring and control equipment	car park and traffic management electric barriers; fire alarm systems that rely on electricity, includes smoke detectors, alarm bells, lighting and sprinklers; electric vehicle charging points with monitoring or other smart features, report basic charge points as category 10; electricity distribution equipment that is a finished product, such as fuse boxes, consumer units and circuit breakers; energy management systems, including sensors and displays; loadbanks (testing systems for electric power supplies); PV inverters, small to medium installations, including micro-inverters (you must report as B2C if they can be used for households or commercially; smart meters, report electricity meters as B2B and "add on" meters or monitors for householders to manage their energy consumption as B2C; thermostats and time switches; traffic lights, temporary and mobile systems are EEE products (when put on the market as a single product), for installed fixed systems (where parts are placed on the market separately) only the lighting and control equipment are EEE products, not the steel posts; x-ray machines installed in airports
10	Automatic dispensers	electric vehicle charge points with basic charging only; photo booths, normally you should report as B2B

Additional categories: 11: display equipment; 12: appliances containing refrigerants, 13: gas discharge lamps and LED light sources. See also: https://www.gov.uk/government/publications/electrical-and-electronic-equipment-eee-covered-by-the-weee-regulations/electrical-and-electronic-equipment-eee-covered-by-the-weee-regulations.

3.2. Hazardous Components in WEEE

The EEE including communication, computing, and entertainment, is a result of the dynamic nature of changing applications that have accelerated technological advancement in all sectors of the economy. Increasing processing, energy efficiency, and speed in the operation of EEE are some of the anticipated specifications to meet product performance [85]. Due to the continuous modification of shapes, functions, and the design of new products and applications, EEE contains a great heterogeneous mixture of materials for durability and efficiency in task execution. There are essential constituents in EEE including critical metals and precious metals (Palladium, Gold, and Silver), and special metals (Tellurium, Indium, Selenium, Tantalum, Bismuth, and Antimony) [86]. For the life cycle and environmental impacts of the EEE, the manufacture of components and their use is often a factor. There is a challenge associated with the use of the WEEE imported as the majority of the imported equipment cannot be reused and hence, they are usually dumped. This exposes the environment to toxic components [87].

Steel and Plastics are the two domineering materials used in EEE, and the weight distribution of the substances differs from value distribution and related environmental pressure. Gold accounts for less than 1% of the device weight (Mobile Phone), and at the same time accounts for over 50% of the material flow created by its production [88]. Due to the heterogeneity of the EEE device to meet several functions and applications, they are not void of substances hazardous to health and threats to the environment. Hazardous substances capable of threatening human health and the environment if not handled and processed accurately in EEE are, Cathode Ray Tubes (CRT) in old TVs and computer monitors, Printed Wiring Board (PWB), capacitors, batteries, and accumulators, toners and ink cartridges, liquid crystal displays (LCDs) and Printed Circuit Board (PCBs) [89].

PWBs contain many metals and Brominated Flame Retardants (BFRs), which are toxic and affect humans and the environment. The hazardous heavy metals found in the components of WEEE are: Cd, Ni, Zn, Pb, Hg, Sn, Ba, Sr, Y, Eu, Se, Cr (iv), which are found in accumulators and batteries, solders, cathode ray tubes, screen coating, memory switches, thermostat, etc. The most prevalent used operation in the processing of WEEE for the extraction of precious metals, like acid leaching and the open burning of dismantled components. This has resulted in the release of toxic metals and pollutants into the environment, which is capable of causing considerable damage to the environment and risk to human health [90]-[92].

Substances and devices in which they can be found as well as their potential effects as regards environment and health safety are shown in **Table 2**.

Table 2. Substances, their occurrence in WEEE, and potential effects as regards environment and health safety [93].

substance	Common source	Possible adverse effects
Lead	Found in cathode-ray tube (CRT) displays, circuit boards, and certain ctronic components.	potent neurotoxin, particularly harmful to children, leading to cognitive impairment and developmental issues. It can also cause long-term damage to the kidneys and reproductive system. Environmentally, lead contamination is difficult to remediate and can persist in ecosystems for decades

Continued

Mercury	Present in fluorescent lamps, older LCD displays, switches, and thermostats.	Mercury is one of the most toxic elements found in WEEE. It bioaccumulates in water sources, posing a severe threat to aquatic life and entering the food chain, where it can cause neurological damage, especially in developing children. Mercury exposure in humans is associated with brain damage, motor dysfunction, and developmental disorders.
Cadmium	Found in rechargeable Ni-Cd batteries, certain circuit boards, and as a stabilizer in plastics.	Cadmium is a known carcinogen and highly toxic to the kidneys. Its environmental persistence means it remains in soil and water for extended periods, contaminating food crops and aquatic ecosystems, leading to bioaccumulation.
Hexavalent Chromium (Cr6+)	Used in anti-corrosion coatings for metal surfaces and in certain electronic components.	Hexavalent chromium is a dangerous carcinogen, known for causing lung cancer and severe respiratory issues. It can also cause skin irritation and damage water sources when released, making it a critical pollutant in WEEE.
Polychlorinated Biphenyls (PCBs)	Found in older capacitors, transformers, and certain electrical components.	PCBs are highly toxic, bioaccumulative, and resistant to degradation. Exposure to PCBs can disrupt endocrine functions, harm the immune system, and cause various cancers. Their persistence in the environment makes them one of the most dangerous pollutants in WEEE.
Brominated Flame Retardants (BFRs)	Used in plastic housings, printed circuit boards, and electrical insulation to reduce fire risk.	BFRs are linked to hormonal imbalances, particularly in thyroid function, and can disrupt endocrine activity. They are persistent environmental pollutants, causing long-term ecological harm, particularly in aquatic environments.
Phthalates	Found in electrical cables, plastic components, and insulation materials.	Phthalates are endocrine disruptors, impacting reproductive health and development. They are especially harmful to children and pregnant women, and exposure can lead to long-term developmental issues.
Chlorofluorocarbons (CFCs)	Found in older refrigeration units, air conditioners, and insulation foam.	Although phased out in many regions due to their harmful impact on the ozone layer, CFCs may still be present in older WEEE. They are potent greenhouse gasses and contribute to ozone depletion, exacerbating global climate change.
Asbestos	Present in older electrical equipment for thermal insulation.	Asbestos fibers are highly carcinogenic, causing lung cancer and mesothelioma. Even small exposures can lead to significant long-term health risks, making it a critical concern in the safe handling of WEEE.
Phosphorus	Found in the phosphor coating inside CRT screens and some lighting devices.	While not hazardous in solid form, phosphorus in powdered or vapor form is toxic if inhaled or ingested, leading to respiratory problems and skin irritation.
Nickel	Used in various batteries, connectors, and metal plating.	Nickel is a common allergen and can cause skin dermatitis. Prolonged exposure can also lead to respiratory issues and is linked to an increased risk of lung cancer.
Hazardous plasticizers and additives	Found in plastic casings, insulation, and flexible wiring.	These additives can leach toxic chemicals into the environment, particularly when burned, posing risks to human health and contributing to air and soil pollution.

Continued

Lithium	Used in lithium-ion batteries found in smartphones, laptops, and other portable devices.	Lithium batteries are highly flammable and can cause fires and explosions if improperly handled, posing significant risks during disposal and recycling processes.

Additional information: https://www.tybet.ro/en/what-dangerous-substances-are-found-in-weee/.

This study proposes the application of the Just-in-time concept and limiting the activities of informal recyclers to WEEE collection to address the numerous challenges associated with informal WEEE management in MTN phone village, Rumukurushi, Port Harcourt, Nigeria.

3.3. Just-in-Time (JIT) Lean Management Principles

Just-in-Time (JIT) is a lean management concept that aims to reduce waste and increase productivity by manufacturing and delivering products exactly when they are required, in the precise amounts needed, and at the appropriate time [94]. Just-in-Time (JIT) is an approach for establishing and sustaining a continuous and smooth flow of products throughout the manufacturing process with minimal delays between processes. It is also used to boost flexibility throughout the entire manufacturing line and supply chain in order to attain a better and faster response to the demand of customers within a restricted cycle period i.e. from assembly to delivery [95]. The JIT concept is viewed as a beneficial strategy, particularly in the industrial sectors of Japan and other developed nations like Australia, the US, and the UK. The adoption of this concept in underdeveloped nations is still in its early stages [96]. Maximising productivity while removing waste is the foundation of the lean production philosophy. Anything that does not add value to a service or product that a customer needs is considered waste. The Toyota Corporation and its system of production are the foundation of lean management. Just-in-time manufacturing, commonly known as the Toyota system of production, is another name for lean management. Lean manufacturing employs a variety of tools and methods to reduce various forms of waste, including overproduction, defects, and waiting times [97]. Businesses that use the Just-In-Time (JIT) technique enjoy numerous advantages, such as lower production costs, better quality, enhanced relationships with suppliers and internal team members, less storage space needed, faster manufacturing, better customer support, etc. Hewlett-Packard was among the first corporations in the West to use Just-In-Time (JIT) in manufacturing. They experienced notable overall improvements at each of their production locations, including inventory reduction by 75%, 50% less storage space, Reworks and scrapped parts/products reduced by 30%, and throughput time reduction by 50% [95]. JIT increases productivity and reduces waste [98]. Informal WEEE management systems can be greatly improved in terms of efficiency, waste reduction, and overall system performance by implementing Just-in-Time (JIT) lean management principles [99]. According to Yang *et al.* [100], and Allers [101], Informal WEEE management stands to stands to gain several benefits by adopting the JIT principles. The benefits are:

- Lower WEEE storage expenses and allow for faster turnover.
- It helps to lower waiting times and enable streamlined processes.
- Prompt management of hazardous materials lowers risks.
- Continuous quality checks and improvement result in improved sorting and recycling results.
- Ability to react fast to changes in the volume and kinds of WEEE gathered.

3.4. A Review of Past Works of Literature

Several efforts have been made in the past and more research is ongoing to manage WEEE. Among the numerous efforts made to manage WEEE previously are as given below:

Ikhlayel [102] (p. 119), made an effort to tackle the public health and environmental challenges associated with informal WEEE recycling. The study designed a systematic concept for WEEE management. The concept is referred to as "integrated e-waste management (IEWM)". The theoretical concept embraces both the management of WEEE and "municipal solid waste" collectively since both use similar disposal and treatment systems. Quantitative data collection was adopted in the study. The outcome of the study proposed the use of "integrated e-waste management" to tackle the public health and environmental challenges associated with informal WEEE management. How has the study addressed the challenges associated with informal recycling using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using the adopted approach. This is because the focus of the study is the use of "integrated e-waste management" to tackle the public health and environmental challenges associated with informal WEEE management.

Rimantho *et al.* [103] (p. 1), attempted to proffer a solution to the public and environmental challenges associated with informal WEEE management in Indonesia by adopting the use of "waste bank system". The study suggested the adoption of "waste bank system" model for the collection of WEEE. A conscious effort was also made in the study to engage DKI Jakarta stakeholders for value support and inputs, while some selected samples were collected for the purpose of the study. Data gathering for the study was achieved with the help of interviews. The outcome of the study proposes waste bank WEEE collection system and calls for the attention of the government with regard to the creation of an enabling environment and regulations for the stakeholders. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges using the combined concepts. This is because the study focused on the use of "waste bank system" without considering measures to control the role of the informal recycler.

Ogbuanya and Afeez [104] (p. 90), made an effort to ensure WEEE approaches applied in the workshops of "electrical/electronic technicians" are advanced for sustainable public health. Data collection was carried out using questionnaires administered to 54 "public health" senior staff as well as 87 Engineering lecturing staff. The data analysis was attained using "percentage, mean, and standard deviation white t-test and ANOVA". The study findings reveal that providing "recycling sites", introducing and applying policies are the major approaches required for the management of WEEE. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges using the combined concepts. This is because the focus of the study was to identify indicators that may be of help.

Juma *et al.* [105] (p. 238), assessed the impact of WEEE stakeholders with respect to the sustainability of WEEE management "by evaluating their course of action". The study proposed a conceptual framework for WEEE management based on the major stakeholders, which was validated using 346 highly positioned workers in key positions in 10 cities in Uganda. Data gathered for the study were analysed using "structural equation modelling (SEM)" method and "partial least square (PLS) technique". The study outcome reveals that the effect of consumer role on WEEE management sustainability is insignificant while the role played by the producer, the media, local government, financial institution, and WEEE handlers have a significant impact on the sustainability of WEEE management. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using the combined concepts and this is because the study only focused on the impact of WEEE stakeholders with respect to the sustainability of WEEE management.

Arya, Gupta, and Bhardwaj [106] attempt to investigate the degree of understanding of informal recyclers, and users (individuals, organisations, and companies) as regards hazards created by WEEE. The study collected data via questionnaires administered to three different WEEE stakeholders namely, organisations, individuals, and those who are into the services of recycling WEEE. The composition of those who responded to the questionnaires are; 10 persons engaged in the services of WEEE recycling, 25 users of electrical and electronic appliances, and 35 organisations considered as users. The study outcome reveals that the individuals and the organisational users lack consciousness of the problems associated with WEEE. There is a lack of ideas as regards legislation on WEEE. There exists an absence of proper channels for the collection of WEEE. Conversely, the recycler in the informal sector who is not aware of the risk associated with WEEE engages in unsafe disposal methods. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using the combined concepts. This is because it primarily focused on the degree of understanding of the informal recyclers and users without considering measures to limit their activities in WEEE management. Besides, the study also failed to identify health, and safety training as an avenue to gain awareness.

Woggsborg and Schröder [107] (p. 1), investigated the emerging impact of private-public partnerships in the management of WEEE in developing countries. The study adopted the use of two different concepts and these are "the triple bottom line approach and the sustainable livelihoods approach" for the analysis of a case study carried out on the "Extended Producer Responsibility (EPR) programme in Nigeria". The study outcome identifies the available opportunities and offers recommendations with respect to the formation of an engagement model that can support informal sector participation by key players such as government agencies, and individuals in both national and international private sectors. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using both approaches. This is because the study focused on the impact of private-public partnerships in the management of WEEE in developing countries.

George, Mapa, and Dinggai [39], tackled WEEE management with households as its main focus using an assessment of the electrical and electronic device composition in the apartments of the people in the chosen area, and the way, in which WEEE is managed. Data collection for the study was achieved using questionnaires. The outcome of the study reveals that the electronic and electrical appliances, that appear the most in the area, are phones. Furthermore, the study outcome also reveals the selected area adopted an unsustainable system of managing WEEE. This is because they don't recycle WEEE, but allow them to remain inside their homes or put them inside the waste bin. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using both approaches because no attempt was made to put a check on the activities of the informal recyclers but recommendations were offered.

Maphosa and Maphosa [108] (p. 1), investigated the status of the sub-Saharan African WEEE management system by performing a critical review of the approach adopted for the management of electronic waste in the location. The study adopted "a systematic literature review (SLR)" approach on past works of literature collected from Sabinet, EBSCO host, and "Web of Science" databases with the help of keywords like recycling or e-waste management, or policy in Africa or sub-Saharan Africa. The study outcome shows that 80% of WEEE management research carried out in sub-Saharan Africa was performed in South Africa, Nigeria, and Ghana. The findings also indicate that the major obstacles to effective WEEE management in the region are inadequate infrastructure for recycling and shortage of viable policies. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using both approaches. This is because the study focus is on the approaches adopted in the location for the management of electronic waste.

Ndunda and Ambole [109] (p. 73), made an effort to tackle the problems introduced by the informal method of WEEE recycling via the creation of "a product-service system" for its management. Those who support the move, from the provision of products to the "provision of systems of products and services" were put in place beside stakeholders' support for WEEE to be managed efficiently. The dematerialization technique was applied via stakeholders' collaboration; this hinders the consumer or recyclers in the informal sector from equipment possession after EOL. The outcome indicates the collaborative effort of those involved determines the success of the technique. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the problem associated with informal WEEE management using both approaches. This is because the focus of the study is to tackle the problems introduced by the informal method of WEEE recycling via the creation of "a product-service system" for its management.

Donny and Suzianti [110] (p. 1636), proposed a WEEE collection application interphase design. The study adopted "a design thinking approach" to the collection of electronic waste with a specific focus on customer needs. In order to gather data for the study, the use of comprehensive interview techniques, personas, prototypes, etc., was adopted. The study outcome reveals that the design-thinking concept enables individuals to formulate "user interphase prototypes" for WEEE collection applications. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using both approaches. This is because the target of the study was the development of prototypes of the user interface for the WEEE collection application.

Aidonis *et al.* [111], created a methodology to recognise an optimal management scheme for WEEE, in order to find another means of integrating WEEE. The study made use of a binary linear programming model to improve the effectiveness of nine (9) options to manage WEEE. Consideration was given to 12 criteria in terms of performance, which cover environmental, financial, social, and technical dimensions were given consideration. The study outcome reveals that the best approach is exporting residues of WEEE and mechanically recycling WEEE. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using both approaches because the technique proposed does not have the potential to tackle the menace of informal WEEE management activities for example recycling. A technique that has the potential to minimize informal WEEE recycling may be more useful.

Mehmood Shad, Ling, and Karim [112] carried out a detailed overview of WEEE management with a specific focus on three countries that are situated close to each other and that are also faced with the problems of WEEE management. These countries are Indonesia, Malaysia, and Singapore. The study outcome suggested that the WEEE management system in place needs to be enhanced, and the flow of WEEE, which is usually free, can be limited by formulating effective WEEE laws. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using both approaches. This is because the study emphasised the need for WEEE free flow to be restricted but failed to consider placing any form of restriction on the informal recyclers.

Mihai *et al*. [14] utilised waste statistical information and "thematic cartography to disclose how WEEE is moved from one geographical location to another. The approach utilized to manage WEEE in numerous locations was examined, for instance, Europe, North America, South America, Oceania, Africa, etc. The findings indicate that inadequate amenity is the idea behind the poor technique of managing WEEE adopted in Africa. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using both approaches as it focuses on the properties of improper management of WEEE. Identifying a useful method that can tackle any of the challenges facing recycling in the informal sector may be helpful.

Franz and Da Silva [113] made an effort to create an alignment with respect to WEEE legislation, management, and generation as well as its interface with reverse logistics, cleaner production, and ecosystem. A qualitative research approach was adopted for the study. The study data, which were obtained from secondary sources were analysed using content analysis. The outcome of the study reveals that the challenges associated with WEEE legislation, management, generation, and all others, can be tackled via the use of circular economy. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using both approaches. This is because the focus of the study is the adoption of circular economy to tackle the challenges associated with WEEE legislation, management, generation, and all others.

Parajuly *et al*. [114] made an effort to investigate many facets of the challenges associated with WEEE management and offer ideas on future problems that may likely emerge. The study outcome indicates the need for future WEEE unforeseen opportunities and challenges to be introduced in public discussions so that such pressing issues can be looked into as early as possible. How has the study addressed the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only? The study did not address the challenges associated with informal WEEE management using both approaches. This is because the focus of the study is to investigate many facets of the challenges associated with WEEE management and offer ideas on future problems that may likely emerge.

4. Research Gap

Several efforts have been made by researchers in the past to proffer a solution to the challenges associated with informal WEEE management, but these challenges still remain. No one has been able to address the challenges associated with informal WEEE management using the application of Just-in-time concept and limiting the activities of informal recyclers to WEEE collection only. This research gap in this field forms the basis of this study. Besides, this study contributes to the existing literature in the area of specialisation.

4.1. WEEE Practice with Health Impacts, Common Activities, and Issues

The electrical electronic sector, which includes computing, Telecommunications, and the entertainment industry is the world's leading industry in terms of the manufacturing of new devices used in its services. The growth recorded economically by the availability of new electronic goods in the market that have replaced obsolete household electrical and electronic equipment is high, which has generated an increasing number of WEEE in the world due to the production of new substitutes yearly. Recent research, [115] posits that valuable elements are recovered from the treatment of WEEE as an alternative and essential means of assessing valuable materials but several challenges emerge from managing the electronic elements present in the WEEE.

At present, there is no globally accepted definition of WEEE. Every region and nation within its legal system sets up definitions and terms of usage. WEEE has diverse definitions from many researchers as it does not have a generally accepted definition [51]. According to EU Directive 2012/19/EU, WEEE is electrical and electronic equipment that is a waste, including all components, consumables, and sub-assemblies that are part of the EE product at the time of discarding the waste. Bhutta, Omar, and Yang [116] conclude e-waste incorporates broad and a growing range of electronic devices ranging from large household EEE, such as refrigerators, air conditioners, personal stereos, cell phones, consumer electronics, and personal computers (PCs) that have been discarded by the original users. Step Initiative [117], considers WEEE term used to cover almost all types of EEE that enter the waste stream, including televisions, computers, mobile phones, white goods, fridges, washing machines, dryers, etc.

Among the list are home entertainment and stereo systems, toys, toasters, kettles, and any household appliances or office EEE with the circuit or electrical components with battery supply for its functionality. In general terms, WEEE consists of obsolete electrical electronics equipment, which can be defined as electrical electronics equipment products, that work with batteries or connect to electricity for their function, and which have been obsolete due to the production of a new model of its kind or no longer wanted by the original owner [86].

4.2. Waste Electrical and Electronics Equipment Trends

Khan *et al*. [118] show that most of the WEEE that is globally generated yearly, which amounts to at least 40 million tonnes finds its way to developing countries as their dumping ground. Nigeria now appears as one of the dumpsites for Asia, US, and European e-waste as shown in **Figure 2**.

Figure 2. E-waste dumpsite in Nigeria with several types of WEEE gathered in bags [50].

In [51], it was observed the amount of WEEE generated worldwide amounts to about "50 million tons". In his work, he emphasized that WEEE production is one of the consequences of the manufacture and usage of electronic devices. Furthermore, the research work indicates that the multipurpose nature of the majority of ICTs has made them desirable to consumers, and as a result of their comparatively short life, there has been a build-up of great capacity of WEEE, which constitutes problems at all levels. This calls for concern as such it has attracted a lot of awareness lately due to its uses and effect on the environment [53]. The projected volume of e-waste generated globally as in Adeola [51] is shown in **Figure 3**.

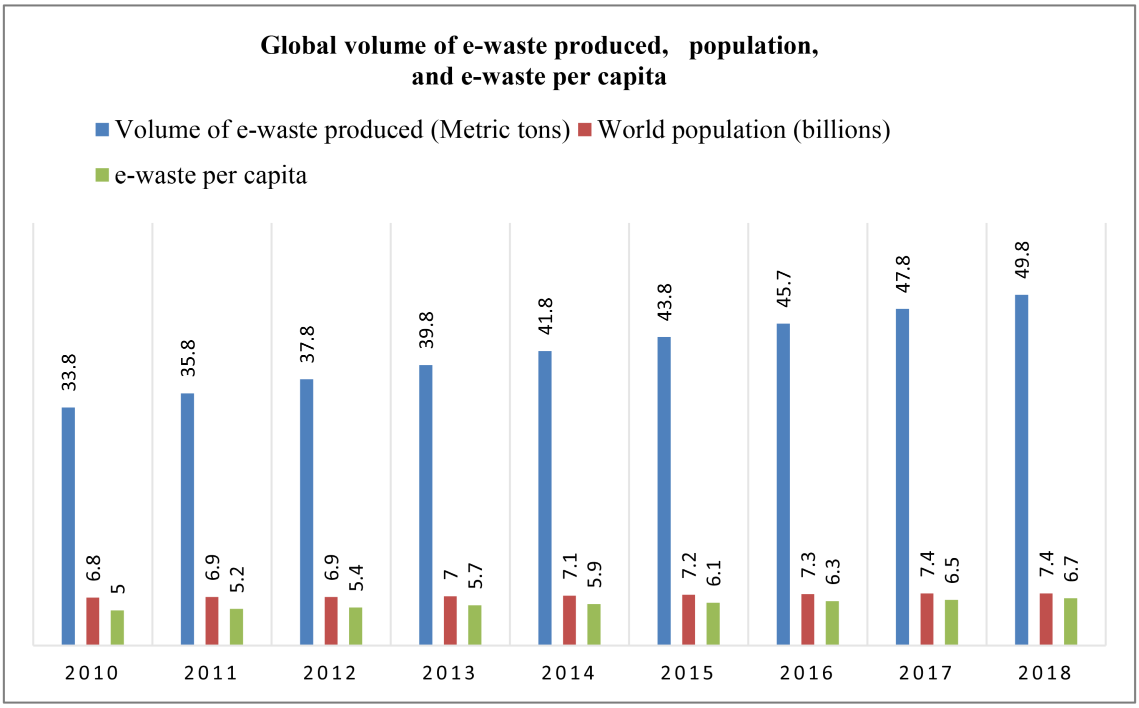

Figure 3. The projected amount of e-waste generated globally.

Similarly, the attempt made by some countries to regulate e-waste as well as the amount of e-waste generated is shown in **Table 3**.

Table 3. Regulatory attempts on e-waste, the quantity, and generators [51].

Year	Volume in (metric tons)	World population (billions)	Per capita
2010	33.8	6.8	5.0
2011	35.8	6.9	5.2
2012	37.8	6.9	5.4
2013	39.8	7.0	5.7
2014	41.8	7.1	5.9
2015	43.8	7.2	6.1
2016	45.7	7.3	6.3
2017	47.8	7.4	6.5
2018 (projected)	49.8	7.4	6.7

The system of information gathering in which waste and secondary products are unknown to national statistics in manufacturing, sale, and trade of new products stands as a barrier worsening the inappropriate database system of the WEEE stream. From records, only a few of the statistics of transported EEE products are categorically designed to differentiate new EEE from used EEE, which turns to WEEE depending on if it is near the EoL period [80]. With the unknown statistics of new EEE and used EEE, Australia, and Hong Kong SAR (China) were the first countries to generate guidelines for differentiating new EEE and used EEE for clarity [119].

South Korea exports each year about 1.8 million used electronics (computers) to China, avoiding the recycling, disposal costs, and likely human and environmental impacts of recycling and disposal within its territory [120]. With the present rate of EEE generation, it can be deduced that the disposal of outdated EEE products is driven primarily by the production of newer versions or close substitutes of such EEE. The developed countries have seen the export of WEEE to Asia and Africa as a preferred option, instead of using the prospect to develop their national recycling infrastructure, develop an innovative design that stops the existence of further toxic material use, and switch to cleaner sustainable technologies [120].

4.3. The Impact of Covid-19

Covid-19 has had a devastating impact on national and global economies, regardless of the extent of the viral impact on particular nations' citizens. The unique coronavirus knows no borders, no religion, and spreads regardless of caste or faith. It is very infectious and quite unpredictable in nature. The world wasn't ready for this type of pandemic, and we are now racing to create a vaccine to prevent its spread [121]. In terms of research, 80% of higher education institutions (HEIs) said that the COVID-19 epidemic had an impact on their institutions' research. The most prevalent impact "of COVID-19 has been the" cancellation or delay of overseas travel (83% of HEIs) and scientific conference cancellation or postponement (81% of HEIs). Furthermore, at slightly more than half of HEIs (52%), "scientific projects are at risk of not being" completed [122] (p. 3). According to UKRI [123], survey, some of the impacts of COVID-19 on research include:

- Shielding or lockdown had a detrimental influence on research time, according to 61% of researchers.
- 58% of respondents claimed that COVID-19 prevented them from doing the planned study.
- More than half of respondents claimed that COVID-19 constraints interfered with other work tasks, such as teaching and administration, which limited their time for research.
- 88% of those surveyed who had parental duties said those obligations interfered negatively with their ability to do research. This was gender-neutral.
- Less commuting and work-related travel, according to 56% and 43% of respondents, respectively, had a favourable influence on their time for research.
- 27% endorsed their study has benefited unexpectedly from COVID-19.

4.4. The Waste Ban in China

The Chinese government's ban on solid waste not only altered the global supply chain for recycled solid waste but diverted it to Malaysia and other Southeast Asian markets. It also prompted the development of new solid waste management infrastructure in these new destination nations, to come up with the capability to handle sudden increases in waste streams [124]. Municipalities and waste management firms from Australia to the United States are looking for alternatives after China said it would no longer serve as the world's primary landfill for recovered garbage. However, experts claim it presents a chance to create better remedies for a culture that is increasingly becoming disposable. The action was taken as an effort to stop a flood of filthy and polluted materials from swamping Chinese processing plants and leaving the nation with yet another environmental issue that is not of its invention [125]. Beginning at the end of 2019, China progressively ceased the importation of waste that is recyclable, that can be substituted by domestic waste. As a result, imports of home waste plastics and waste metal and electrical appliance scraps were prohibited by the end of 2017, and the end of 2018, respectively. The China Ban or China Shock is a sudden shift in policy that significantly affected the world market for plastic garbage [125].

China has created and disposed of a sizable amount of WEEE being the largest manufacturer, user, and importer of electrical and electronic equipment. China produced the most WEEE in the world, at 7.2 Mt, in 2016, and roughly 3.66 Mt (16.055 million units) of WEEE were recycled. However, the majority of the collection is made by lone collectors and dealers, whose work is loose and unsustainable because it is low-tech, low-paying, unrecorded, and unregulated. This is mostly due to the fact that an efficient formal WEEE collecting system, which is the first stage in recycling and is essential to its scope, scale, efficiency, and effectiveness, has not been fully established or consolidated [126] [127].

4.5. How to Dispose WEEE

As in CI [128], WEEE can be disposed of in three major ways namely: Landfill, incineration, and recycling. In the case of the landfill, WEEE is disposed of by burying them. Due to the hazardous nature of WEEE coupled with the scarcity of space at most sites used as landfills, dumping of WEEE at sites used as landfills needs to be discouraged. Several hazards associated with landfilling as in Annamalai [129] are shown in **Figure 4**.

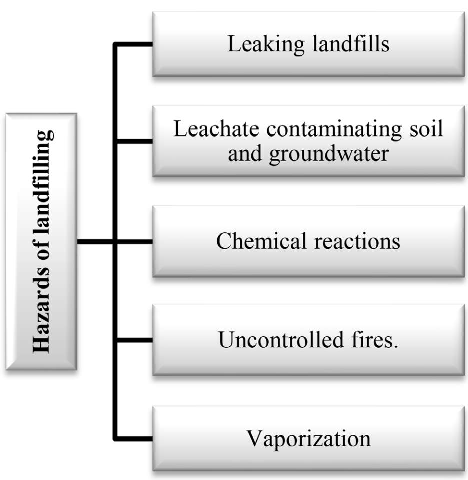

Figure 4. Hazards of landfills.

For elements that are volatile and biologically not degradable e.g., Cd, Hg, CFC, or persistent for example Polychlorinated biphenyls (PCB), treatment by land-filling is not environmentally friendly. Due to this mixture of e-waste materials, it is not feasible to eliminate the risk involved. In the case of incineration, the WEEE is destroyed through burning, and the burning of the WEEE is done at a temperature, that is high. Some of the benefits of this disposal method include: the energy can be recovered from the burning elements and used, secondly, there is depletion in the volume of WEEE. It also has demerits and these are: it adds considerably to the amount of mercury and cadmium emitted annually, heavy metal content in the WEEE is usually not released to the atmosphere via emission, they are converted to slag and residues from gas, and during disposal, this waste still shows up in the environment [128] [129]. Some of the associated hazards with the incineration method of waste disposal are shown in **Figure 5**.

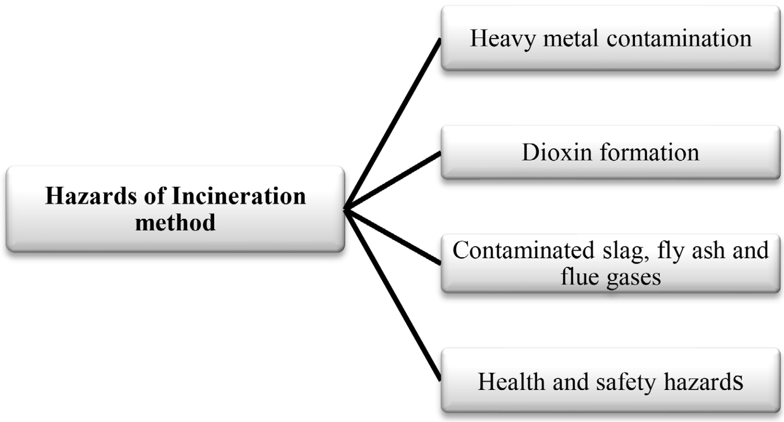

Figure 5. Hazards associated with incinerator method of waste disposal.

The recycling method of waste disposal converts WEEE or some elements of WEEE into brand-new forms. This helps to cut down on the use of new raw materials as the existing materials are converted to new forms [128]. In this method, elements of WEEE that are composed of harmful elements e.g., Hg, PCB, plastics, etc., are dismantled. The recyclers are exposed to danger by working with no masks and technical skills in an enclosed location with poor ventilation. According to Annamalai [129], some of the hazards due to the recycling method include:

- The presence of mercury affects the development and functioning of the brain.
- This method of WEEE disposal exposes the environment and human health to risk.
- There is a risk of damage to the human kidney, blood system, peripheral and central nervous system due to the presence of lead.

In Okorhi, Omotor, and Aderemi [130], the record has it, that the collection, handling, and refurbishing of WEEE is carried out by informal recyclers, who are illiterates, of a low standard, without experience. They are usually "undocumented business" persons, they usually lack training and investment, and they go about the streets and waste dumps with their handcarts to collect or buy in rare cases abandoned WEEE and other metal scraps, which "contain" important elements like Iron, Brass, Copper, Aluminium, etc. Ohajinwa *et al.* [131], explain that the recycling of most of the WEEE generated is carried out in an informal/unsafe way such that toxic elements are released into the environment. According to Mihai *et al.* [132], the informal WEEE recycling practice appears to dominate the Nigerian WEEE market. These informal recycling activities happened often in the backyards or little workshops in Nigerian cities (Port-Harcourt) where primary methods of manual disassembly and open burning are practiced. Primitive techniques like the performance of dismantling manually, melting of metals, acid dipping, and open burning are often utilised to recover valuable materials from WEEE. The informal recycler does not adopt optimized methodologies for material recovery, for example, metals are usually recovered via heating WEEE in a hot plate or open flame. In some instances, WEEE is shredded mechanically to help recover valuable metals [133]-[136].

The WEEE is recycled by removing components or valuable materials, and these materials are: integrated circuit (IC) plastics, condenser, Cathode ray tubes (CRTs), Printed wiring board (PWB), and metals, which were part of the system that are reprocessed directly as reusable components for raw materials [137]. The commonly practiced process of harnessing most of the materials is through an open burning system that is injurious to human health and the environment [136]. The actors in the informal sectors are the cart pushers, the scavengers (those who sort and recover materials that can be reused or recycled), the resource merchants, and the recyclers [138]. Despite the problems associated with the informal WEEE management system, it serves as a source of employment and a means of livelihood for several families [139].

The importance of recycling is not centered on WEEE requiring treatment, but on enhancing the recovery of valuables in the discarded WEEE from the dumpsites. The crude methods employed by the informal recyclers, cannot adequately recuperate the potential toxic elements (PTEs) in the EEE [140]. Thereby the call for funding by all stakeholders for the upgrading of the recycling sector and proper integration of the sectors in Nigeria is a necessity. However, studies have revealed that informal recycling methods and activities like dismantling, open burning of plastics and wire, and indiscriminate disposal led to a significant level of potentially toxic elements and persistent organic pollutant emission to air, soil, and water. The existing pathways to the soil, environment, and impact on humans are described in the below methods and activities of WEEE management in the informal sector [48] [141].

Studies reveal that informal recycling activities such as open burning of wires and plastics, dismantling, and unregulated disposal result in the release of significant levels of heavy metals, and persistent organic pollutants to the soil, air, and underground water and surface [140] [142]. However, a study carried out by Ezeudu and Ezeudu [142], shows that Nigeria does not have the capacity for formal recycling methods, maybe due to the lack of modern recycling facilities in the country. Conversely, Omokaro [143] (p. 18), explains that the effort made to commence formal recycling in Nigeria failed due to "consumption habits", political, social, economic "and cultural context", which aids the services of the informal recyclers.

Presently, the WEEE management system at MTN phone village, in Port Harcourt city, Nigeria, is carried out by informal recyclers who lack the basic knowledge on the prevention, reuse, recycling, recovery, and disposal. This study attempts to change the existing WEEE management practice in the location as the focus is to prevent the harmful and primitive style of WEEE management carried out by recyclers in the informal sector in the area as well as other regions faced with a similar practice. Furthermore, the moment the activities of informal recyclers are drastically reduced at MTN phone village in Port Harcourt, Nigeria, the problems associated with recycling in the informal sector will come to an end.

4.6. WEEE Management System Proposed for MTN Phone Village, Rumukurushi, Port Harcourt, Nigeria

This study recommended the reduction of the activities of informal recyclers in MTN phone village, Rumukurushi in Port Harcourt, Nigeria via the combination of two different approaches namely:

- Recovering WEEE from residents, informal recyclers, and the remaining part of the public for sorting, processing, treatment, and recycling by government-approved agencies.
- Application of the just-in-time (JIT) lean management principles to the current WEEE management system in the location.

The WEEE management system ensures that only government-approved agencies are allowed to manage WEEE. WEEE is collected from residents, informal recyclers, and the remaining part of the public and this will help to cut down informal recycling and the challenges associated with it. The application of the just-in-time concept should be applied by government-approved agencies after WEEE collection/gathering. Furthermore, the dismantling of WEEE should be carried out by experienced and trained government personnel to ensure that the dismantled WEEE materials follow appropriate processing such as re-use, further treatment, refining, etc.

5. Main Conclusion

This study reviews WEEE management system and this embraces the concept of WEEE management. It covers the methodology of the literature review (which includes the inclusion and exclusion criteria), WEEE category, hazardous components in WEEE, a review of past works of literature, the research gap, WEEE practice with health impacts, common activities, and issues, Waste electrical electronics equipment trends. Other areas reviewed are the impact of COVID-19*,* the waste ban in China, how to dispose of WEEE, WEEE management system proposed for MTN phone village, Rumukurushi in Port Harcourt, Nigeria, and finally, the main conclusion. This study identified a research gap in the area of study. It also contributes to the existing knowledge in the field of specialisation. Furthermore, the study recommended, restricting the activities of informal recyclers to WEEE collection coupled with the adoption of the Just-in-time (JIT) lean management principles to the current WEEE management system the location, and other areas faced with similar challenges.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Shahabuddin, M., Nur Uddin, M., Chowdhury, J.I., Ahmed, S.F., *et al.* (2023) A Review of the Recent Development, Challenges, and Opportunities of Electronic Waste (E-Waste). *International Journal of Environmental Science and Technology*, **20**, 4513-4520. https://doi.org/10.1007/s13762-022-04274-w

[2] Dogbatsey, L., Obour, P.B., Barima, A.O. and Schandorf, C. (2023) Review of the Health and Safety Awareness of E-Waste Management Activities at Two Sites in the Accra Metropolitan Area, Ghana. *International Journal of Science and Research Archive*, **10**, 374-386. https://doi.org/10.30574/ijsra.2023.10.1.0727

[3] Dogbatsey, L., Barima, A.O., Yandam, R. and Schandorf, C. (2024) Assessment of the Health and Safety Culture at the E-Waste Facilities at the Greater Accra Metropolitan Area of Ghana. *International Journal of Research and Innovation in Social Science*, **VIII**, 530-542. https://doi.org/10.47772/IJRISS.2024.805040

[4] Okwu, O., Hursthouse, A., Viza, E. and Idoko, L. (2022) New Models to Reduce the Health Risks of Informal WEEE Recyclers in MTN Phone Village, Rumukurushi, Port Harcourt, Nigeria. *Toxics*, **10**, Article 84. https://doi.org/10.3390/toxics10020084

[5] Shittu, O.S., Williams, I.D. and Shaw, P.J. (2021) Global E-Waste Management: Can WEEE Make a Difference? A Review of E-Waste Trends, Legislation, Contemporary Issues and Future Challenges. *Waste Management*, **120**, 549-563. https://doi.org/10.1016/j.wasman.2020.10.016

[6] Okwu, O., Viza, E., Hursthouse, A. and Idoko, L. (2022) Menace of Informal Waste Electrical and Electronic Equipment Recycling at MTN Phone Village, Rumukurushi, Port Harcourt, Nigeria. *International Journal of Environmental Science and Technology*, **20**, 9745-9756. https://doi.org/10.1007/s13762-022-04663-1

[7] Konya, R.S., Babatunde, B.B. and Iniefe, D. (2015) Assessment of E-Waste Status in Port Harcourt City and Its Environs. *Environmental Sciences*, **3**, 45-66. https://doi.org/10.12988/es.2015.521

[8] Kalamaras, G., Kloukinioti, M., Antonopoulou, M., *et al.* (2021) The Potential Risk of Electronic Waste Disposal into Aquatic Media: The Case of Personal Computer Motherboards. *Toxics*, **9**, Article 166. https://doi.org/10.3390/toxics9070166

[9] Danz, P., Aryan, V., Möhle, E. and Nowara, N. (2019) Experimental Study on Fluorine Release from Photovoltaic Backsheet Materials Containing PVF and PVDF during Pyrolysis and Incineration in a Technical Lab-Scale Reactor at Various Temperatures. *Toxics*, **7**, Article 47. https://doi.org/10.3390/toxics7030047

[10] Amadi, A.I. and Chijioke, A.K. (2018) Economic and Environmental Sustainability

of Informal Sector Recycling of Construction and Demolition Waste in Nigeria. *AASCIT Journal of Environment*, **3**, 1-10.

[11] Ohajinwa, C.M., Van Bodegom, P.M., Vijver, M.G. and Peijnenburg, W.J.G.M. (2017) Health Risks Awareness of Electronic Waste Workers in the Informal Sector in Nigeria. *International Journal of Environmental Research and Public Health*, **14**, Article 911. https://doi.org/10.3390/ijerph14080911

[12] Leung, A.O.W., Duzgoren-Aydin, N.S., Cheung, K.C. and Wong, M.H. (2008) Heavy Metals Concentrations of Surface Dust from E-Waste Recycling and Its Human Health Implications in Southeast China. *Environmental Science & Technology*, **42**, 2674-2680. https://doi.org/10.1021/es071873x

[13] Starovoytova, D. (2018) Solid Waste Management (SWM) at a University Campus (Part 1/10): Comprehensive-Review on Legal Framework and Background to Waste Management, at a Global Context. *Journal of Environmental & Earth Sciences*, **8**, 68-116.

[14] Mihai, F., Gnoni, M.-G., Meidiana, C., Ezeah, C. and Elia, V. (2019) Waste Electrical and Electronic Equipment (WEEE): Flows, Quantities and Management, a Global Scenario. In: Prasad, M.N.V. and Vithanage, M., Eds., *Electronic Waste Management and Treatment Technology*, Elsevier Inc., 1-35. https://doi.org/10.1016/B978-0-12-816190-6.00001-7

[15] Awere, E., Obeng, P.A., Bonoli, A. and Obeng, P.A. (2020) E-Waste Recycling and Public Exposure to Organic Compounds in Developing Countries: A Review of Recycling Practices and Toxicity Levels in Ghana. *Environmental Technology Reviews*, **9**, 1-19. https://doi.org/10.1080/21622515.2020.1714749

[16] Bi, X., Thomas, G.O., Jones, K.C., *et al.* (2007) Exposure of Electronics Dismantling Workers to Polybrominated Diphenyl Ethers, Polychlorinated Biphenyls, and Qrganochlorine Pesticides in South China. *Environmental Science & Technology*, **41**, 5647-5653. https://doi.org/10.1021/es070346a

[17] Bimir, M.N. (2020) Revisiting E-Waste Management Practices in Selected African Countries. *Journal of the Air & Waste Management Association*, **70**, 659-669. https://doi.org/10.1080/10962247.2020.1769769

[18] Kitila, A.W. and Woldemikael, S.M. (2019) Waste Electrical and Electronic Equipment Management in the Educational Institutions and Governmental Sector Offices of Addis Ababa, Ethiopia. *Waste Management*, **85**, 30-41. https://doi.org/10.1016/j.wasman.2018.12.007

[19] Mihai, F.-C. and Gnoni, M.-G. (2017) E-Waste Management as a Global Challenge (Introductory Chapter). *E-Waste in Transition-From Pollution to Resource*, **14**, 1-18.

[20] Zhu, M., Shen, M.J., Liang, X.X., *et al.* (2021) Identification of Environmental Liquid-Crystal Monomers: A Class of New Persistent Organic Pollutants-Fluorinated Biphenyls and Analogues—Emitted from E-Waste Dismantling. *Environmental Science & Technology*, **55**, 5984-5992. https://doi.org/10.1021/acs.est.1c00112

[21] Needhidasan, S., Samuel, M. and Chidambaram, R. (2014) Electronic Waste—An Emerging Threat to the Environment of Urban India. *Journal of Environmental Health Science and Engineering*, **12**, Article No. 36. https://doi.org/10.1186/2052-336X-12-36

[22] Forti, V., Baldé, C.P., Kuehr, R. and Bel, G. (2020) The Global E-Waste Monitor 2020: Quantities, Flows, and the Circular Economy Potential. http://ewastemonitor.info/

[23] Mostafa, T.M. and Sarhan, D.S. (2018) Economic Feasibility Study of E-Waste Recycling Facility in Egypt. *Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **5**, 26-35. https://doi.org/10.5109/1936214

[24] Ciftci, M. and Cicek, B. (2017) E-Waste: A Review of CRT (Cathode Ray Tube) Recycling. *Research & Reviews: Journal of Material Sciences*, **5**, 1-17. https://doi.org/10.4172/2321-6212.1000170

[25] Lecler, M.T., Zimmermann, F., Silvente, E., Clerc, F., Chollot, A. and Grosjean, J. (2015) Exposure to Hazardous Substances in Cathode Ray Tube (CRT) Recycling Sites in France. *Waste Management*, **39**, 226-235. https://doi.org/10.1016/j.wasman.2015.02.027

[26] Ledwaba, P. and Sosibo, N. (2017) Cathode Ray Tube Recycling in South Africa. *Recycling*, **2**, Article 4. https://doi.org/10.3390/recycling2010004

[27] Xu, Q. Yu, M. Kendall, A., He, W., Li, G. and Schoenung, J.M. (2016) Environmental and Economic Evaluation of Cathode Ray Tube (CRT) Funnel Glass Waste Management Options in the United States. In: Kirchain, R.E., Blanpain, B., *et al*., Eds., *REWAS* 2016 *towards Materials Resource Sustainability*, Springer, 309-310. https://doi.org/10.1007/978-3-319-48768-7_48

[28] Ali, M.H.H. and Al-Qahtani, K.M. (2012) Assessment of Some Heavy Metals in Vegetables, Cereals and Fruits in Saudi Arabian Markets. *Egyptian Journal of Aquatic Research*, **38**, 31-37. https://doi.org/10.1016/j.ejar.2012.08.002

[29] Ismičić-Tanjo, D., Huremović, J., Selović, A. and Šehović, E. (2021) Human Health Risk Assessment of Mercury in Soil-Plants System. *International Journal of Environmental Research*, **15**, 797-805. https://doi.org/10.1007/s41742-021-00357-7

[30] Natasha, Shahid, M., Khalid, S., Bibi, I., *et al.* (2020) A Critical Review of Mercury Speciation, Bioavailability, Toxicity and Detoxification in Soil-Plant Environment: Ecotoxicology and Health Risk Assessment. *Science of the Total Environment*, **711**, Article 134749. https://doi.org/10.1016/j.scitotenv.2019.134749

[31] Ahen, F. and Amankwah-Amoah, J. (2021) Sustainable Waste Management Innovations in Africa: New Perspectives and Research Agenda for Improving Global Health. *Sustainability*, **13**, Article 6646. https://doi.org/10.3390/su13126646

[32] Gebeyehu, H.R. and Bayissa, L.D. (2020) Levels of Heavy Metals in Soil and Vegetables and Associated Health Risks in Mojo Area, Ethiopia. *PLOS ONE*, **15**, e0227883. https://doi.org/10.1371/journal.pone.0227883

[33] Zhou, H., Yang, W.-T., Zhou, X., *et al.* (2016) Accumulation of Heavy Metals in Vegetable Species Planted in Contaminated Soils and the Health Risk Assessment. *International Journal of Environmental Research and Public Health*, **13**, Article 289. https://doi.org/10.3390/ijerph13030289

[34] Attia, Y., Soori, P.K. and Ghaith, F. (2021) Analysis of Households' E-Waste Awareness, Disposal Behavior, and Estimation of Potential Waste Mobile Phones towards an Effective E-Waste Management System in Dubai. *Toxics*, **9**, Article 236. https://doi.org/10.3390/toxics9100236

[35] Clemens, S. (2006) Toxic Metal Accumulation, Responses to Exposure and Mechanisms of Tolerance in Plants. *Biochimie*, **88**, 1707-1719. https://doi.org/10.1016/j.biochi.2006.07.003

[36] Nagajyoti, P.C., Lee, K.D. and Sreekanth, T.V.M. (2010) Heavy Metals, Occurrence and Toxicity for Plants: A Review. *Environmental Chemistry Letters*, **8**, 199-216. https://doi.org/10.1007/s10311-010-0297-8

[37] Omorogieva, O.M. and Tonjoh, J.A. (2020) Bioavailability of Heavy Metal Load in Soil, Groundwater, and Food Crops Manihot Esculenta and *Carica papaya* in Dumpsite Environment. *International Journal of Environmental Science and Technology*, **17**, 4853-4864. https://doi.org/10.1007/s13762-020-02812-y

[38] Sagbara, G., Zabbey, N., Sam, K. and Nwipie, G.N. (2020) Heavy Metal Concentration in Soil and Maize (*Zea mays* L.) in Partially Reclaimed Refuse Dumpsite 'Borrow-Pit' in Port Harcourt, Nigeria. *Environmental Technology & Innovation*, **18**, Article 100745. https://doi.org/10.1016/j.eti.2020.100745

[39] George, F., Mapa, M.T. and Dinggai, S.A. (2019) IOP CoPreliminary Study on Waste Electrical and Electronic Equipment (WEEE) Management by Households in the Kota Kinabalu City. *IOP Conference Series: Earth and Environmental Science*, **286** Article 012023. https://doi.org/10.1088/1755-1315/286/1/012023

[40] Hossain, R., Nekouei, R.K., Mansuri, I. and Sahajwalla, V. (2019) Sustainable Recovery of Cu and Sn from Problematic Global Waste: Exploring Value from Waste Printed Circuit Boards. *ACS Sustainable Chemistry & Engineering*, **7**, 1006-1017. https://doi.org/10.1021/acssuschemeng.8b04657

[41] Hsu, E., Durning, C.J., West, A.C. and Park, A.H.A. (2021) Enhanced Extraction of Copper from Electronic Waste via Induced Morphological Changes Using Supercritical CO_2. *Resources, Conservation and Recycling*, **168**, Article 105296. https://doi.org/10.1016/j.resconrec.2020.105296

[42] Li, Z., Diaz, L.A., Yang, Z.Y., *et al.* (2019) Comparative Life Cycle Analysis for Value Recovery of Precious Metals and Rare Earth Elements from Electronic Waste. *Resources, Conservation and Recycling*, **149**, 20-30. https://doi.org/10.1016/j.resconrec.2019.05.025

[43] Tanısalı, E., Özer, M. and Burat, F. (2020) Precious Metals Recovery from Waste Printed Circuit Boards by Gravity Separation and Leaching. *Mineral Processing and Extractive Metallurgy Review*, **42**, 24-37. https://doi.org/10.1080/08827508.2020.1795849

[44] Wang, Z., Zhang, B. and Guan, D. (2016) Take Responsibility for Electronic-Waste Disposal. Nature Publishing Group.

[45] Wang, J., Chen, S.Y., Zeng, X.F., *et al.* (2021) Recovery of High Purity Copper from Waste Printed Circuit Boards of Mobile Phones by Slurry Electrolysis with Ammonia-Ammonium System. *Separation and Purification Technology*, **275**, Article 119180. https://doi.org/10.1016/j.seppur.2021.119180

[46] Zhang, K., Schnoor, J.L. and Zeng, E.Y. (2012) E-Waste Recycling: Where Does It Go from Here? *Environmental Science & Technology*, **46**, 10861-10867. https://doi.org/10.1021/es303166s

[47] Cole, C., Gnanapragasam, A., Cooper, T. and Singh, J. (2019) An Assessment of Achievements of the WEEE Directive in Promoting Movement Up the Waste Hierarchy: Experiences in the UK. *Waste Management*, **87**, 417-427. https://doi.org/10.1016/j.wasman.2019.01.046

[48] Ferronato, N. and Torretta, V. (2019) Waste Mismanagement in Developing Countries: A Review of Global Issues. *International Journal of Environmental Research and Public Health*, **16**, Article 1060. https://doi.org/10.3390/ijerph16061060

[49] Shah Khan, S., Aziz Lodhi, S., Akhtar, F. and Khokar, I. (2014) Challenges of Waste of Electric and Electronic Equipment (WEEE): Toward a Better Management in a Global Scenario. *Management of Environmental Quality*, **25**, 166-185. https://doi.org/10.1108/MEQ-12-2012-0077

[50] Lawal, S. (2020) Nigeria Has Become an E-Waste Dumpsite for Europe, US and Asia. Trtworld. https://www.trtworld.com/magazine/nigeria-has-become-an-e-waste-dumpsite-for-europe-us-and-asia-24197

[51] Adeola, F.O. (2018) 2-WEEE Generation and the Consequences of Its Improper Disposal. In: Vegliò, F. and Birloaga, I., Eds., *Waste Electrical and Electronic Equipment Recycling*, Woodhead Publishing, 13-31. https://doi.org/10.1016/B978-0-08-102057-9.00002-0

[52] (2024) Global Waste Management Outlook 2024. United Nations Environment Programme. https://www.unep.org/ietc/resources/report/global-waste-management-outlook-2024

[53] Dagiliūtė, R., Zabulionis, D., Sujetovienė, G. and Žaltauskaitė, J. (2019) Waste of Electrical and Electronic Equipment: Trends and Awareness among Youths in Lithuania. *Waste Management & Research*, **37**, 95-101. https://doi.org/10.1177/0734242X18806999

[54] Sarkhoshkalat, M.M., Afkham, A., Manesh, M.B. and Sarkhosh, M. (2024) Circular Economy and the Recycling of E-Waste. In: Kasinathan, K., Ladchumananandasivam, R. and Mohamed, S.B., Eds., *New Technologies for Energy Transition Based on Sustainable Development Goals*, Springer, 319-354. https://doi.org/10.1007/978-981-97-2527-4_16

[55] Twagirayezu, G., Irumva, O., Huang, K., *et al.* (2022) Environmental Effects of Electrical and Electronic Waste on Water and Soil: A Review. *Polish Journal of Environmental Studies*, **31**, 2507-2525. https://doi.org/10.15244/pjoes/144194

[56] Palaniandy, P., Yusoff, M.S., Wang, L.K. and Wang, M.-H.S. (2022) Electronic and Electrical Equipment Waste Disposal. In: Wang, L.K., Wang, M.H.S. and Hung, Y.T., Eds., *Solid Waste Engineering and Management*, Handbook of Environmental Engineering, 115-161. https://doi.org/10.1007/978-3-030-96989-9_3

[57] Jayasiri, G., Herat, S. and Kaparaju, P. (2023) Management of Small WEEE: Future Directions for Australia. *Sustainability*, **15**, Article 13543. https://doi.org/10.3390/su151813543

[58] Fadaei, A. (2022) E-Waste Management Status Worldwide: Major Challenges and Solutions. *Proceedings of the International Academy of Ecology and Environmental Sciences*, **12**, 281-293. http://www.iaees.org/publications/journals/piaees/online-version.asp

[59] Van Yken, J., Boxall, N.J., Cheng, K.Y., *et al.* (2021) E-Waste Recycling and Resource Recovery: A Review on Technologies, Barriers and Enablers with a Focus on Oceania. *Metals*, **11**, Article 1313. https://doi.org/10.3390/met11081313

[60] Mudali, U.K., Patil, M., Saravanabhavan, R. and Saraswat, V.K. (2021) Review on E-Waste Recycling: Part I—A Prospective Urban Mining Opportunity and Challenges. *Transactions of the Indian National Academy of Engineering*, **6**, 547-568. https://doi.org/10.1007/s41403-021-00216-z

[61] Chaine, C., Hursthouse, A.S., McLean, B., *et al.* (2022) Recycling Plastics from WEEE: A Review of the Environmental and Human Health Challenges Associated with Brominated Flame Retardants. *International Journal of Environmental Research and Public Health*, **19**, Article 766. https://doi.org/10.3390/ijerph19020766

[62] Botle, A., Salgaonkar, S., Tiwari, R., Barabde, G. and Herlekar, M. (2024) Circular Waste Management System and Greenhouse Gases Reduction. In: Kumar, V., Bhat, S.A., Kumar, S. and Verma, P., Eds., *Environmental Engineering and Waste Management*, Springer, 649-684. https://doi.org/10.1007/978-3-031-58441-1_22

[63] Wu, S., Kaden, N. and Dröder, K. (2023) A Systematic Review on Lithium-Ion Battery Disassembly Processes for Efficient Recycling. *Batteries*, **9**, Article 297. https://doi.org/10.3390/batteries9060297

[64] Corder, G.D., Golev, A. and Giurco, D. (2015) "Wealth from Metal Waste": Translating Global Knowledge on Industrial Ecology to Metals Recycling in Australia. *Minerals Engineering*, **76**, 2-9. https://doi.org/10.1016/j.mineng.2014.11.004

[65] Xavier, L.H., Ottoni, M. and Abreu, L.P.P. (2023) A Comprehensive Review of Urban Mining and the Value Recovery from E-Waste Materials. *Resources, Conservation and Recycling*, **190**, Article 106840. https://doi.org/10.1016/j.resconrec.2022.106840

[66] Hodgkinson, S. and Schoeman, T. (2021) E-Waste Recycling Behaviour: A Case Study of the City of Johannesburg. https://www.researchgate.net/publication/371508364

[67] Ryan-Fogarty, Y., Baldé, C.P., Wagner, M. and Fitzpatrick, C. (2023) Uncaptured Mercury Lost to the Environment from Waste Electrical and Electronic Equipment (WEEE) in Scrap Metal and Municipal Wastes. *Resources, Conservation and Recycling*, **191**, Article 106881. https://doi.org/10.1016/j.resconrec.2023.106881

[68] Ioannidis, M. (2024) Reducing Waste in Warehouse Operations through EWM System Optimization: A Case Study of SAP-Enabled Solutions. Πανεπιστήμιο Πειραιώς.

[69] Airaksinen, J.-P. (2023) Effect of Recycling Packaging Materials in Finnish Organizations. LAB University of Applied Sciences. https://www.theseus.fi/bitstream/handle/10024/800959/Airaksinen%20Juho.pdf?sequence=2

[70] Ali, S. and Shirazi, F. (2023) The Paradigm of Circular Economy and an Effective Electronic Waste Management. *Sustainability*, **15**, Article 1998. https://doi.org/10.3390/su15031998

[71] Fontana, A., Barni, A., Leone. D., *et al.* (2021) Circular Economy Strategies for Equipment Lifetime Extension: A Systematic Review. *Sustainability*, **13**, Article 1117. https://doi.org/10.3390/su13031117

[72] Ramasubramanian, B., Tan, J., Chellappan, V. and Ramakrishna, S. (2023) Recent Advances in Extended Producer Responsibility Initiatives for Plastic Waste Management in Germany and UK. *Materials Circular Economy*, **5**, Article No. 6. https://doi.org/10.1007/s42824-023-00076-8

[73] Chaine, C., Hursthouse, A.S., McLellan, I., Viza, E. and Miller, J. (2023) The Challenge of Plastic Management for Waste Electrical and Electric Equipment Recycling in the Global South: A Case Comparison between Europe and Latin America. *Recycling*, **8**, Article 71. https://doi.org/10.3390/recycling8050071

[74] Menikpura, S.N.M., Santo, A. and Hotta, Y. (2014) Assessing the Climate Co-Benefits from Waste Electrical and Electronic Equipment (WEEE) Recycling in Japan. *Journal of Cleaner Production*, **74**, 183-190. https://doi.org/10.1016/j.jclepro.2014.03.040

[75] Lu, B., Song, X., Yang, J. and Yang, D. (2017) Comparison on End-of-Life Strategies of WEEE in China Based on LCA. *Frontiers of Environmental Science & Engineering*, **11**, Article No. 7. https://doi.org/10.1007/s11783-017-0994-7

[76] Song, Q. and Li, J. (2015) A Review on Human Health Consequences of Metals Exposure to E-Waste in China. *Environmental Pollution*, **196**, 450-461. https://doi.org/10.1016/j.envpol.2014.11.004

[77] Ardi, R. and Leisten, R. (2016) Assessing the Role of Informal Sector in WEEE Management Systems: A System Dynamics Approach. *Waste Management*, **57**, 3-16. https://doi.org/10.1016/j.wasman.2015.11.038

[78] Dwivedy, M. and Mittal, R.K. (2010) Estimation of Future Outflows of E-Waste in India. *Waste Management*, **30**, 483-491.

[79] Singh, N., Li, J. and Zeng, X. (2016) Solutions and Challenges in Recycling Waste Cathode-Ray Tubes. *Journal of Cleaner Production*, **133**, 188-200. https://doi.org/10.1016/j.jclepro.2016.04.132

[80] Ongondo, F.O., Williams, I.D. and Keynes, S. (2011) Estimating the Impact of the "Digital Switchover" on Disposal of WEEE at Household Waste Recycling Centres in England. *Waste Management*, **31**, 743-753. https://doi.org/10.1016/j.wasman.2010.11.005

[81] Chancerel, P., Rotter, V.S., Ueberschaar, M., Marwede, M., Nissen, N.F. and Lang, K.-D. (2013) Data Availability and the Need for Research to Localize, Quantify and Recycle Critical Metals in Information Technology, Telecommunication and Consumer Equipment. *Waste Management & Research*, **31**, 3-16. https://doi.org/10.1177/0734242X13499814

[82] Yu, J., Williams, E., Ju, M. and Shao, C. (2010) Managing E-Waste in China: Policies, Pilot Projects and Alternative Approaches. *Resources*, *Conservation and Recycling*, **54**, 991-999. https://doi.org/10.1016/j.resconrec.2010.02.006

[83] GAP Group (2020) Your Guide to Categories of WEEE. https://gapgroupuk.com/resources/latest-news/your-guide-to-categories-of-weee/

[84] WEEE (2020) 10 Categories of Electrical and Electronic Equipment Covered by WEEE Directive. http://weeeregistry.com/categories-of-electrical-and-electronic-equipment-covered-by-WEEE-directive.html

[85] Kumar, A. and Dixit, G. (2018) An Analysis of Barriers Affecting the Implementation of E-Waste Management Practices in India: A Novel ISM-DEMATEL Approach. *Sustainable Production and Consumption*, **14**, 36-52. https://doi.org/10.1016/j.spc.2018.01.002

[86] Chancerel, P. and Rotter, S. (2009) Recycling-Oriented Characterization of Small Waste Electrical and Electronic Equipment. *Waste Management*, **29**, 2336-2352. https://doi.org/10.1016/j.wasman.2009.04.003

[87] Iwenwanne, V. (2019) Nigeria's E-Waste Mountain. https://resource.co/article/nigerias-e-waste-mountain

[88] Ongondo, F.O., Williams, I.D. and Cherrett, T.J. (2011) How Are WEEE Doing? A Global Review of the Management of Electrical and Electronic Wastes. *Waste Management*, **31**, 714-730. https://doi.org/10.1016/j.wasman.2010.10.023

[89] Salhofer, S. and Tesar, M. (2011) Assessment of Removal of Components Containing Hazardous Substances from Small WEEE in Austria. *Journal of Hazardous Materials*, **186**, 1481-1488. https://doi.org/10.1016/j.jhazmat.2010.12.030

[90] Birloaga, I., De Michelis, I., Ferella, F., Buzatu, M. and Vegliò, F. (2013) Study on the Influence of Various Factors in the Hydrometallurgical Processing of Waste Printed Circuit Boards for Copper and Gold Recovery. *Waste Management*, **33**, 935-941. https://doi.org/10.1016/j.wasman.2013.01.003

[91] Fu, F. and Wang, Q. (2011) Removal of Heavy Metal Ions from Wastewaters: A Review. *Journal of Environmental Management*, **92**, 407-418. https://doi.org/10.1016/j.jenvman.2010.11.011

[92] Grant, K., Goldizen, F.C., Sly, P.P.D., *et al.* (2013) Health Consequences of Exposure to E-Waste: A Systematic Review. *The Lancet Global Health*, **1**, E350-E361. https://doi.org/10.1016/S2214-109X(13)70101-3

[93] Kaya, M. (2016) Recovery of Metals and Nonmetals from Electronic Waste by Physical and Chemical Recycling Processes. *Waste Management*, **57**, 64-90. https://doi.org/10.1016/j.wasman.2016.08.004

[94] Suwanda, S. (2023) Implementation of Just-in-Time (JIT) Policy in Increasing Production Efficiency of Manufacturing Companies. *Journal Arbitrase*: *Economy*, *Man-*

agement and Accounting, **1**, 61-69.
http://paspama.org/index.php/Arbitrase/article/view/73

[95] Zensimu (2024) The Principles of Just in Time (JIT).
https://zensimu.com/skills/just-in-time/

[96] Lara, A.C., Menegon, E.M.P., Sehnem, S. and Kuzma, E. (2022) Relationship between Just in Time, Lean Manufacturing, and Performance Practices: A Meta-Analysis. *Gestão & Produção*, **29**, 1-21. https://doi.org/10.1590/1806-9649-2022v29e9021

[97] Demir, S. and Paksoy, T. (2023) Just-in-Time and Lean Management. In: Paksoy, T. and Deveci, M., Eds., *Smart and Sustainable Operations and Supply Chain Management in Industry* 4.0, CRC Press, 223-236.
https://doi.org/10.1201/9781003180302-11

[98] Siddiqui, A. (2022) The Importance of Just in Time (JIT) Methodology and Its Advantages in Health Care Quality Management Business—A Scoping Review. *Biomedical Journal of Scientific & Technical Research*, **42**, 33317-33325.
https://doi.org/10.26717/BJSTR.2022.42.006701

[99] Okwu, O., Hursthouse, A., Viza, E. and Idoko, L. (2021) Enhancement of WEEE Management Practices in MTN Phone Village, Rumukurushi, Port Harcourt, Nigeria. *Recycling*, **6**, Article 77. https://doi.org/10.3390/recycling6040077

[100] Yang, J., Xie, H., Yu, G. and Liu, M. (2021) Achieving a Just-in-Time Supply Chain: The Role of Supply Chain Intelligence. *International Journal of Production Economics*, **231**, Article 107878. https://doi.org/10.1016/j.ijpe.2020.107878

[101] Allers, T. (2024) Just in Time (JIT) Inventory: A Comprehensive Guide.
https://intuendi.com/resource-center/just-in-time/

[102] Ikhlayel, M. (2018) An Integrated Approach to Establish E-Waste Management Systems for Developing Countries. *Journal of Cleaner Production*, **170**, 119-130.
https://doi.org/10.1016/j.jclepro.2017.09.137

[103] Rimantho, D., Syaiful, S., Nurfaida and Sulandari, U. (2022) Electronic Waste Bank Model as a Solution for Implementing Circular Economy: Case Study DKI Jakarta-Indonesia. *Frontiers in Built Environment*, **8**, Article 1030196.
https://doi.org/10.3389/fbuil.2022.1030196

[104] Ogbuanya, T.C. and Afeez, Y.S. (2019) Advancing Electronic Waste Management Techniques among Electrical/Electronic Technicians' Workshops for Sustainable Healthy Society. *Insights in Mining Science & Technology*, **1**, 90-104.

[105] Juma, N.S., Samali, M., Judith, A. and Ibrahim, N.A. (2022) Towards a Sustainable Electronic Waste Management in Uganda: A stakeholder Perspective. *African Journal of Environmental Science and Technology*, **16**, 238-251.
https://doi.org/10.5897/AJEST2021.3088

[106] Arya, S., Gupta, A. and Bhardwaj, A. (2018) Electronic Waste Management Approaches-A Pilot Study in Northern Indian States. *International Journal of Waste Resources*, **8**, 1-5.

[107] Woggsborg, A. and Schröder, P. (2019) Nigeria's E-Waste Management: Extended Producer Responsibility and Informal Sector Inclusion. *Journal of Waste Resources and Recycling*, **1**, Article 102. https://doi.org/10.15744/2766-5887.1.102

[108] Maphosa, V. and Maphosa, M. (2020) E-Waste Management in Sub-Saharan Africa: A Systematic Literature Review. *Cogent Business & Management*, **7**, Article 1814503.
https://doi.org/10.1080/23311975.2020.1814503

[109] Ndunda, H.K. and Ambole, L.A. (2018) Product-Service Systems Design for E-Waste Management: A Case Study of Waste Electrical and Electronic Equipment Centre in

Nairobi County. *Proceedings of the* 2*nd Innovation Research Symposium*, 6 March 2018, Nairobi, 73-81. https://api.semanticscholar.org/CorpusID:249178210

[110] Donny, A. and Suzianti, A. (2022) Development of User Interface Design for Electronic Waste Collection with a Design Thinking Approach. *Proceedings of the* 7*th North American International Conference on Industrial Engineering and Operations Management*, Orlando, 12-14 June 2022, 1636-1646.

[111] Aidonis, D., Achillas, C., Folinas, D., Keramydas, C. and Tsolakis, N. (2019) Decision Support Model for Evaluating Alternative Waste Electrical and Electronic Equipment Management Schemes—A Case Study. *Sustainability*, 11, Article 3364. https://doi.org/10.3390/su11123364

[112] Mehmood Shad, K., Ling, S.T.Y. and Karim, M.E. (2020) Comparative Study on E-waste Management and the Role of the Basel Convention in Malaysia, Singapore, and Indonesia: A Way Forward. *Indonesia Law Review*, **10**, Article 5. https://doi.org/10.15742/ilrev.v10n1.596

[113] Franz, N.M. and Luiz Da Silva, C. (2022) Waste Electrical and Electronic Equipment (WEEE): Global and Contemporary Challenge to Production Chains and the Urban Environment. *Gestão & Produção*, **29**, 1-19. https://doi.org/10.1590/1806-9649-2022v29e6621

[114] Parajuly, K., *et al.* (2019) Future E-Waste Scenarios. 1-34. https://www.unep.org/ietc/resources/publication/future-e-waste-scenarios

[115] D'Adamo, I., Rosa, P. and Terzi, S. (2016) Challenges in Waste Electrical and Electronic Equipment Management: A Profitability Assessment in Three European Countries. *Sustainability*, **8**, Article 633. https://doi.org/10.3390/su8070633

[116] Bhutta, M.K.S., Omar, A. and Yang, X. (2011) Electronic Waste: A Growing Concernin in Today's Environment. *Economics Research International*, **2011**, Article 474230. https://doi.org/10.1155/2011/474230

[117] Step, I. (2020) What Is E-Waste. http://www.step-initiative.org/e-waste-challenge.html

[118] Khan, S.S., Lodhi, S.A., Akhtar, F. and Khokar, I. (2014) Challenges of Waste of Electric and Electronic Equipment (WEEE): Toward a Better Management in a Global Scenario. *Management of Environmental Quality*, **25**, 166-185. https://doi.org/10.1108/MEQ-12-2012-0077

[119] Chung, S., Lau, K. and Zhang, C. (2011) Generation of and Control Measures for, E-Waste in Hong Kong SAR. *Waste Management*, **31**, 544-554. https://doi.org/10.1016/j.wasman.2010.10.003

[120] Zoeteman, B.C.J., Krikke, H.R. and Venselaar, J. (2010) Handling WEEE Waste Flows: On the Effectiveness of Producer Responsibility in a Globalizing World. *The International Journal of Advanced Manufacturing Technology*, **47**, 415-436. https://doi.org/10.1007/s00170-009-2358-3

[121] Kumar Verma, A. and Prakash, S. (2023) Impact of COVID-19 on Environment and society. *Journal of Global Biosciences*, **9**, 7352-7363.

[122] Marinoni, G., Van'T Land, H. and Jensen, T. (2020) The Impact of Covid-19 on Higher Education. https://ihe.bc.edu/pub/bynpvaze

[123] UK Research and Innovation (2023) Survey Findings of the Impact of COVID-19 on Researchers. https://www.ukri.org/news/survey-findings-of-the-impact-of-covid-19-on-researchers/

[124] Song, N., McLellan, I., Liu, W., Wang, Z. and Hursthouse, A. (2021) The Waste Ban in China: What Happened Next? Assessing the Impact of New Policies on the Waste Management Sector in China. *Environmental Geochemistry and Health*, **45**, 1117-1131. https://doi.org/10.1007/s10653-021-01101-y

[125] Katz, C. (2019) Piling Up: How China's Ban on Importing Waste Has Stalled Global Recycling. Yale School of the Environment. https://e360.yale.edu/features/piling-up-how-chinas-ban-on-importing-waste-has-stalled-global-recycling

[126] Zhang, Q. (2021) China's Policy and Finding Ways to Prevent Collapse in WEEE Processing in the Context of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal. *International Environmental Agreements*: *Politics*, *Law and Economics*, **21**, 693-710. https://doi.org/10.1007/s10784-021-09540-9

[127] Zuo, L., Wang, C. and Sun, Q. (2020) Sustaining WEEE Collection Business in China: The Case of Online to Offline (O2O) Development Strategies. *Waste Management*, **101**, 222-230. https://doi.org/10.1016/j.wasman.2019.10.008

[128] Citizens Information (2020) Waste from Electrical and Electronic Equipment (WEEE). https://www.citizensinformation.ie/en/environment/waste-and-recycling/weee/

[129] Annamalai, J. (2015) Occupational Health Hazards Related to Informal Recycling of E-Waste in India: An overview. *Indian Journal of Occupational and Environmental Medicine*, **19**, 61-65. https://doi.org/10.4103/0019-5278.157013

[130] Okorhi, J.O., Omotor, D. and Aderemi, H.O. (2020) Wastes from Industrialized Nations: A Socio-Economic Inquiry on E-waste Management for the Recycling Sector in Nigeria. In: El-Din Saleh, H., Ed., *Assessment and Management of Radioactive and Electronic Wastes*, IntechOpen, 1-22.

[131] Ohajinwa, C.M., Van Bodegom, P.M., Vijver, M.G., Olumide, A.O., Osibanjo, O. and Peijnenburg, W.J.G.M. (2018) Prevalence and Injury Patterns among Electronic Waste Workers in the Informal Sector in Nigeria. *Injury Prevention*, **24**, 185-192. https://doi.org/10.1136/injuryprev-2016-042265

[132] Mihai, F.C. (2019) Electronic Waste Management in Romania: Pathways for Sustainable Practices. In: Prasad, M.N.V., Vithanage, M. and Borthakur, A., Eds., *Handbook of Electronic Waste Management*: *International Best Practices and Case Studies*, Elsevier Inc., 533-551. https://doi.org/10.1016/B978-0-12-817030-4.00024-3

[133] Bin Hameed, H., Ali, Y. and Petrillo, A. (2020) Environmental Risk Assessment of E-Waste in Developing Countries by Using the Modified-SIRA Method. *Science of The Total Environment*, **733**, Article 138525. https://doi.org/10.1016/j.scitotenv.2020.138525

[134] Butturi, M.A., Marinelli, S., Gamberini, R. and Rimini, B. (2020) Ecotoxicity of Plastics from Informal Waste Electric and Electronic Treatment and Recycling. *Toxics*, **8**, Article 99. https://doi.org/10.3390/toxics8040099

[135] Luo, P., Bao, L.J., Wu, F.C., Li, S.M. and Zeng, E.Y. (2014) Health Risk Characterization for Resident Inhalation Exposure to Particle-Bound Halogenated Flame Retardants in a Typical E-Waste Recycling Zone. *Environmental Science & Technology*, **48**, 8815-8822. https://doi.org/10.1021/es501973d

[136] Onwughara, I.N., Nnorom, I.C. and Kanno, O.C. (2010) Issues of Roadside Disposal Habit of Municipal Solid Waste, Environmental Impacts and Implementation of Sound Management Practices in Developing Country "Nigeria". *International Journal of Environmental Science and Development*, **1**, 409-418. https://doi.org/10.7763/IJESD.2010.V1.79

[137] Salhofer, S. (2018) E-waste Collection and Treatment Options: A Comparison of Approaches in Europe, China and Vietnam, In: Maletz, R., Dornack, C. and Ziyang, L., Eds., *Handbook of Environmental Chemistry*, Springer Verlag, 227. https://doi.org/10.1007/698_2017_36

[138] Alabi, R.A. and Wohlmuth, K. (2019) The Case of Sustainable Management of Waste in Germany (and Bremen) and Practical Lessons for Nigeria (and Lagos). http://www.iwim.uni-bremen.de

[139] Ohajinwa, C.M. (2020) Environmental and Health Impacts of Informal Electronic Waste Recycling. Leiden University. http://hdl.handle.net/1887/66320

[140] Gangwar, C., Choudhari, R., Chauhan, A., Kumar, A., Singh, A. and Tripathi, A. (2019) Assessment of Air Pollution Caused by Illegal E-Waste Burning to Evaluate the Human Health Risk. *Environment International*, **125**, 191-199. https://doi.org/10.1016/j.envint.2018.11.051

[141] Williams, E., Kahhat, R., Allenby, B., Kavazanjian, E., Kim, J. and Xu, M. (2008) Environmental, Social, and Economic Implications of Global Reuse and Recycling of Personal Computers. *Environmental Science & Technology*, **42**, 6446–6454. https://doi.org/10.1021/es702255z

[142] Ezeudu, O.B. and Ezeudu, T.S. (2019) Implementation of Circular Economy Principles in Industrial Solid Waste Management: Case Studies from a Developing Economy (Nigeria). *Recycling*, **4**, Article 42. https://doi.org/10.3390/recycling4040042

[143] Omokaro, B.I. (2018) Moving Forward Sustainably: Material and Social Conditions of Electronic Waste Management in Nigeria, University of Jyväskylä.