I.J. Information Engineering and Electronic Business, **2022, 5, 15-23**
Published Online on October 8, 2022 by MECS Press (http://www.mecs-press.org/)
DOI: 10.5815/ijieeb.2022.05.02

Sustainable E-waste Management at Higher Education Institutions' Data Centres in Zimbabwe

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Received: 02 March 2022; Revised: 16 April 2022; Accepted: 24 May 2022; Published: 08 October 2022

Abstract: The study's objective was to examine the management of data centre electronic waste (e-waste) by Zimbabwean universities to ensure environmental sustainability and reduce the epidemiological effect of indiscriminate disposal of e-waste. The 21st century has seen universities adopting Information and Communication Technology (ICT) to automate processes and support technology-based learning, raising demands for data centre infrastructure to run applications and store data. In developing countries, obsolete ICT equipment is indiscriminately discarded with municipal waste into landfills and often scavenged to extract valuable metals using rudimentary methods such as heating, burning, and leaching, causing environmental and epidemiological crises. E-waste is the fastest growing stream of solid waste that contains scarce rare earth minerals and toxic elements, presenting an opportunity and a crisis during disposal. The study utilised the descriptive study design through a quantitative questionnaire to collect data from ICT Directors and Managers from Zimbabwean universities. Results show that a fifth of the participants had operational procedures for handling e-waste. A tenth of the participants knew of the existence of national policies. Obsolete equipment was kept in storerooms, while some were discarded with municipal trash. Most respondents were aware of the effect of e-waste, which is attributed to responsible management. Most participants redeployed decommissioned data centre equipment to less intense processing environments; 28% had labelled bins and designated e-waste collection points. In reducing their carbon footprint, three-quarters of the participants virtualised servers and stored data on the cloud, and 10% of the institutions practised take-back schemes and located data centres onsite. Universities should legislate the management of data centres to control carbon emissions, energy and e-waste and contribute to green initiatives. Partnerships with developed countries for data centre design and high-end recycling should be encouraged, thus creating employment, generating income for institutions and reducing the epidemiological effects.

Index Terms: Electronic waste, data centre, higher educational institutions, green initiatives, sustainability

1. Introduction

The industrial revolution witnessed the exploitation of non-renewable energy in production systems, raising pollution and a higher carbon footprint. Information Communication Technology (ICT) has become a game-changer as jobs that did not require its use are now heavily dependent on ICT. Although many people in developing countries joined the digital revolution late, the past few years have witnessed unprecedented ICT adoption supporting every area of human life [1]. This has not spared the education sector, where learners use computers for searching for information, collaboratively learn, network and learn remotely. For many developing countries, the COVID-19 pandemic accelerated digital transformation as many aspects of human activity had to be digitally mediated. The COVID-19 pandemic has driven data traffic and storage to unprecedented levels, driving investments in data centre equipment and adopting digital solutions as governments instituted lockdowns, restricting face-to-face meetings to curb the spread of the virus. The outbreak of COVID-19 has glaringly exposed humanity's dependency on digital technologies for remote work, learning and social interactions. Over 1.5 billion learners were affected, and most educational institutions adopted remote-based learning [2].

ICT improves learners' acquisition of knowledge and 21st-century skills through ubiquitous access to learning content, simulations, and augmented reality. The influence of ICT on education has been transformational, fostering student-teacher relationships and creating new learning opportunities. For many developing countries, ICT promises to transform learning by increasing student learning opportunities through equitable access that bridges the digital divide. Advances in ICT such as 5G and LTE networks, Internet of Things (IoT), blockchain, augmented reality, cloud computing, artificial intelligence (AI) and big data are fuelling ICT adoption (Manganelli et al. [3]. Nicholas et al. [4]

note that every sector of the economy, including education, is undergoing digital transformation and is adopting AI, big data, and IoT to support teaching and learning. Thus, dependence on ICT fuels the demand for mobile devices, servers, connectivity, and associated devices, driving the demand for data storage [5].

The unprecedented adoption of ICT devices by organisations and individuals fuels e-waste, forcing governments, industry leaders and regulators to battle for solutions to protect the environment and public health. From the 52 MT of e-waste produced globally, only 22.9% was recycled, with Africa only recycling 0.1%, while the rest of its e-waste is discarded through informal means that damage the environment and human health [6]. E-waste is the fastest growing stream of solid waste that contains scarce rare earth minerals and toxic elements, presenting an opportunity and a crisis during its disposal. ICT deployment and use should strive to keep the environment and planet healthy by reducing environmental pollution.

Educational institutions invest in data centres to ensure continuous access to e-Learning servers and support services for students and staff. Data centres are usually remotely located to provide a secure location for processing large amounts of data. Patrizio [7] notes that data centres consume about 3% of global electrical power and have other effects on the environment, such as the disposal of obsolete equipment and the effect of cooling systems on the environment. In the IT value chain, data centres have the largest environmental impact, and there has been worldwide concern regarding their management. To meet environmental targets and avert the e-waste disaster, data centres must promote the three R's, reduce, reuse and recycle. Power consumption, cooling and disposal of obsolete IT equipment are among the top e-waste contributors. There are concerns about designing energy-efficient data centres. Manganelli et al. [3] note a growing trend in free cooling, whereby nearby water sources drive data centre cooling infrastructure instead of relying on electrical-powered systems. There is a growing trend in establishing data centres out of the city environment to utilise natural airflow and water bodies, with Notley [5] noting that city-based data centres are susceptible to hotter temperatures generated by air conditioning systems.

Zimbabwe has witnessed a surge in Internet access over the past few years, increasing from 500,000 in 1995 to over 9 million in 2020 [2]. The increase has been fuelled by the remarkable growth in mobile phone subscriptions and computer or laptop ownership. The past decades saw Zimbabwe adopting the look east policy, where second-hand and cheap products were imported from China and Dubai to bridge the digital divide without considering the environmental and epidemiological impact [8]. Like most developing countries, Zimbabwe is yet to enact policies to tackle the mounting e-waste problems. Only 20% of African countries have e-waste policies [6]; the lack of national e-waste policies has hindered the enactment of local-level data centre management policies to foster e-waste management resulting in unceasing e-waste management challenges. Energy consumption, cooling and disposal of obsolete data centre equipment are some of the top environmental issues that must be tackled in most developing countries for sustainable management of obsolete IT equipment.

A. Green technology initiatives

Green initiatives involve using eco-accommodating means to reduce the adverse effects of technology on the environment and support initiatives to reduce hazardous and rare-earth metals in manufacturing IT components [9]. Higher education institutions (HEI) support green initiatives by adopting IT, which reduces driving and travelling to attend lectures, reduces printing and less electricity usage and cooling by limiting the usage of lecture rooms. Hopkinson and James [10] assert that adopting IT advances a green environment as it supports a clean environment. Sadh [9] notes that educational institutions should utilise e-materials and lessen printing to reduce the carbon footprint. This will require institutions to invest in data centres for improved access to more e-materials and support green initiatives.

In developed countries, top institutions are rated based on their environmentally responsible philosophy, which has seen them retain and attract the best human resources and students [11]. Developed countries have invested in high-technology infrastructure for recycling e-waste in line with public health and environmental concerns [2,6,12]. Institutions in developing countries should craft policies that reduce carbon emissions and locate data centres in places that reduce negative environmental impact [5]. Governments can support green initiative platforms by offering incentives to those found compliant. Lepawsky and Connolly [12] noted that incentives such as tax rebates for individuals and institutions recycling e-waste and regulating informal e-waste could promote green initiatives. If done properly, recovering some precious metals from e-waste is a green computing initiative that promotes the environment's sustainability by reducing mining activities [13]. Promoting green technology is through technology convergence, where multiple devices and functionalities are integrated into a single device to minimise the environmental and human health impact during device disposal [14].

One of the measures HEIs can utilise to raise environmental sustainability is awareness through social media [9]. Institutions can use social media to share their ongoing initiatives and appeal to staff and students to manage and promote greening initiatives. Hamid et al. [15] commended institutions for using social media to promote ecological sustainability and awareness of the effect of e-waste on the environment.

Like most developing countries, Zimbabwe is experiencing growth in e-waste accumulation as institutions and individuals embrace new technologies to participate in the global market, remote work and learning induced by COVID-19 [16]. When ICT equipment becomes obsolete, it is indiscriminately discarded with municipal waste into landfills and often scavenged to extract valuable metals by heating, burning, and other methods, causing environmental and epidemiological crises. Researchers should raise awareness and influence responsible practices on managing data centre e-waste produced by educational institutions. This study evaluates how HEIs in Zimbabwe manage data centre e-waste to promote green initiatives and the steps taken to raise ecological and environmental sustainability.

2. Literature Review

ICT is disruptive, affecting every sphere of human life, including education. HEIs have adopted a technology-based curriculum to serve students who frequently text and search for information on the web. Adopting technology by the students is more natural as most of them are accustomed to it, as millennials and Generation Z. Most university students belong to Generation Z, and Twenge [17] describes them as those born after 1995. Keengwe and Georguna [18] also note that HEIs are obligated to adopt ICT to meet the needs of the millennials, a generation that wants to construct its learning processes and collaborate in teams to create new knowledge. Studies show immense advantages regarding technology integration, such as supporting students in critical thinking and high-order skills, collaboration when creating projects and peer learning [19,20].

Technology diffusion in higher education has come with environmental pressure as equipment becomes obsolete, fuelling e-waste. Institutions and students rapidly dispose of electronic products, which are still working, as new models are introduced rapidly with new functionality [21]. Many developing countries are importing second-hand computers to participate in the knowledge economy and bridge the digital divide; for example, over 500 containers loaded with used electronics dock in Lagos every month [22]. Clark and Matharu [23] estimate that developing countries such as China, India, South Africa and Nigeria will witness a 500% increase in e-waste generation by 2020.

One way to protect the environment is using green technologies, where carbon emissions are reduced by adopting environmentally-friendly equipment, which reduces the depletion of the ozone layer [24]. These initiatives should target producers to manufacture recyclable gadgets with minimum toxic elements and reduce the usage of rare earth minerals. Green initiatives involve enhancing stakeholder knowledge of the environmental impact of e-waste and encouraging recycling and green technologies [24].

The costs of recycling and disposing of e-waste are high; Alam and Bahauddin [21] note that it costs up to $US2,000 to dispose of a tonne of hazardous waste in developed countries and about $US50 in Africa. Lack of policies and weak labour laws make e-waste disposal cheaper in Africa, as it is done without considering human health and environmental consequences [2,16]. Mageto et al. [25] conclude that most developing countries have no formal e-waste management policies, and e-waste disposal is managed by the informal sector, which is challenging to regulate. This has seen many developed countries exporting e-waste to Africa.

About 80% of the world's high-tech trash composed of toxic elements and precious minerals is exported to Africa and Asia, with China receiving 50% while Nigeria accounts for 25% [26]. Perkins et al. [27] note that some second-hand donations of used computers are unsuitable, coupled with illegal exports, making developing countries experience challenges in managing e-waste [16,27]. Research shows that Africa generated 2.2 Mt of e-waste, and only 4 Kt were recycled, less than 1% of the waste generated [25]. Scholars report that e-waste is Africa's fastest-growing stream of solid waste; it grows at 20 percent per annum, putting a strain on the environment and human health [2,25]. Cucchiella et al. [28] concluded that e-waste was growing at five percent per annum, and projections reveal that developing countries will dispose of over 600 million computers compared to 300 million by the developed world.

There is limited data to quantify the amount of e-waste generated by developing countries [29]. McCann [30] notes that it is challenging to estimate e-waste output as the sector is highly informal and most imports are illegal. Besides data centre equipment, Mageto et al. [25] noted that academic institutions in Africa were the largest producers of e-waste as they procured second-hand computers for their students due to low budgets. Alam and Bahauddin [21] note that non-working electronics constitute 75-95 percent per shipment, a clear dumping strategy by developed countries.

Developing countries are experiencing astronomical increases in the adoption of ICTs, driven by the desire to participate in the global economy and reduce the digital divide. This has seen second-hand, unusable and unrepairable equipment being shipped to countries that often do not have any policy and legislation to protect the environment and public health [25]. Another study in Bangladesh noted that inadequate policies, infrastructure, uncoordinated collection, and lack of awareness were hindering e-waste management efforts [21]. The University of Griffith in Queensland enacted policies supporting eCycling, where all e-waste is deposited in a container known as the green box and is also used by the public [31].

A. Effects of toxic elements on health

In developing countries, e-waste management is highly informal, thus determining handling and disposal methods. Poor and marginalised communities use rudimentary methods to recover precious minerals from e-waste [47]. In developing countries, e-waste is collected with municipal waste and finds its way into landfills, threatening the environment and human health [21]. Airborne dioxins and heavy metals are released through rudimentary methods such as burning and leaching, leading to environmental and epidemiological crises [22]. Research reveals that various health problems in Ghana, such as respiratory, gastrointestinal, dermatological, and other contagious diseases, are common at the Agbogbloshie e-waste landfill [32].

Children were observed burning cables and dismantling CRT monitors, often using chisels and stones to break plastic casings [29]. Metal extraction is done by dipping printed circuit boards into acid or burning, exposing workers to inhalation of toxic gases and contaminating the environment [21]. Researchers concluded that breastfeeding women could transfer hexabromocyclododecanes (HBCDs) and other toxins to infants via breast milk [33]. Earlier studies noted that toxic chemicals like cadmium, chromium, zinc, and phthalate are transferred to the fetus during pregnancy and found in newborn babies [34]. Open burning and burying e-waste causes diseases such as thyroid, lung cancer, reproductive health problems and other neurological disorders [35].

Scholars revealed that heavy chemicals in e-waste, such as chromium, cadmium and nickel, were associated with the umbilical cord, blood and the foetus's DNA damage, wheezing and coughing in children [36]. Exposure to e-waste alters the biomarker responsible for immunity assessment for infectious diseases, thereby impeding immunity from vaccination [37]. Workers use rudimentary methods to inhale hazardous compounds like cadmium and other pollutants [29]. The World Health Organisation reports that more than 18 million children are involved in informal e-waste recycling and are susceptible to contracting many diseases through dermal exposure [38]. Aquifers and water bodies near e-waste dumpsites are contaminated, affecting areas further from the dumpsite [39]. Soil samples, river sediments and underground water are contaminated by e-waste, causing skin damage, gastric ulcers, nausea and headaches [40]. Garlapati [41] reports that cadmium in one cell phone battery can contaminate over 600 cubic metres of water. Indiscriminate disposal of e-waste has resulted in large parts of groundwater in Nigeria being polluted and condemned for human use [26].

B. The economic value of e-waste

The United Nations reports that over 55 billion euros can be realised annually if proper recycling is employed to recover the gold, silver and other raw materials in e-waste [42]. Annually, 300 tonnes of gold are used to manufacture electronic devices globally [23]. Clark and Matharu [23] referred to e-waste as urban mining, where minerals with high concentration and purity than traditional underground mines can be recovered. Materials recovered from most of the e-waste contain elements that can be used to manufacture new products [26]. E-waste recycling employs many people; recyclers in Ghana earn up to US$285 per month, while those in Nigeria earn about US$100 [29]. E-waste is a lucrative business, as Oteng-Ababio and Amankwaa [43] reported that scrap dealers made US$50 per day, intermediaries make US$35 per day, while e-waste informal workers made US$3.50 per day, which is two and half times the average earnings of informal workers in other sectors.

3. Methodology

The study's objective was achieved through a quantitative descriptive study that evaluated e-waste management at data centres in HEIs in Zimbabwe by assessing knowledge level, practices, policy adherence and awareness. The methodology allows the researcher to gather data from the participants, which can be analysed quantitatively for testing awareness, disposal, handling, recycling and management practices. The study's questionnaire was developed and pilot-tested before deploying on Google forms. The questionnaire has five sections. The first section captures the demographic information of the respondents, and the next section evaluates the general e-waste management; the following targets data centre management and environmental sustainability when disposing of e-waste, use of social media for awareness and advocacy, and the last section evaluates policies and strategies used to manage data centre e-waste. The study used a 5-point Likert scale with a total of 36 questions. Quantitative data were collected between August and September 2021. The study population consisted of ICT Directors and ICT Managers from 24 public and private universities in Zimbabwe selected through purposive sampling. Of the targeted 100 respondents, 73 completed the questionnaire, giving a response rate of 73%. Data were analysed using Statistical Package for the Social Science (SPSS) version 26. Descriptive statistics such as mean, percentage and standard deviation were also used to analyse the data from the survey.

4. Results and Discussion

A. Demographics of the participants

The participants' demographic characteristics are presented in Table 1. The results show that almost three-quarters (74.6%) of the respondents were male, while females constituted 25.4%. Regarding age, half (50.68%) were 41-50 years, with 2.7% aged over 50, as shown in Table 1. Almost two-thirds (61.6%) had an MSc, and BSc were 35.7%, and 2.7% were PhD holders. The majority (64.3%) had 1-9 years of experience, 26.1% had 10-19 years, and 9.6% had over 20 years of experience.

Table 1. Demographic profile of the participants

Demographic variables	Demographic variables values	Frequency	Percentage
Gender	Male	53	74.6%
	Female	21	25.4%

Age	Less than 30 years	19	26.12%
	31-40 years	37	50.68%
	41-50 years	15	20.5%
	Over 50 years	2	2.7%
Qualification	Undergraduate-BSc	26	35.7%
	Postgraduate-MSc	45	61.6%
	Postgraduate-PhD	2	2.7 %
Experience	1-9 years	47	64.3%
	10-19 years	19	26.1%
	Over 20 years	7	9.6 %

B. Use of data centre equipment that has been decommissioned

University ICT Directors and Managers were asked how they handled decommissioned data centre equipment, as shown in Table 2. The common practice was to keep this equipment in the storeroom, where a mean score of 4.7 (90.4%) and a standard deviation of 0.7 was observed. The results show that the country does not have any meaningful recycling. This is demonstrated by a mean score of 1.0 (20%) of institutions that took their data centre waste to recycling institutions. This is similar to the Klang Valley in Malaysia, which recycled less than 10% of its 98.5 metric tons of e-waste [31]. Most participants discarded e-waste with trash with a mean score of 4.2 (84%), and the standard deviation was 0.58. In a related study, Agamuthu et al. [31] reported that 90% of respondents across Malaysian universities kept e-waste in storerooms, with a third of the universities donating used computer equipment to schools and other institutions. The third-ranked method was redeploying some of the equipment to less intense data processing environments with a mean score of 4.0 (80%) and a standard deviation of 0.42. Again very few institutions sold their data centre waste to scrap dealers. This means there is an accumulation of data centre waste at the institutions. Knudsen [44] reported that Columbia University collected 40.5 metric tons of e-waste recycled. E-waste recycling in developing countries is mainly informal; all the respondents confirmed that they were unaware of any formal recyclers. This creates a problem because institutions could send obsolete data centre equipment to informal recyclers.

Table 2. Handling of data centre equipment that has been decommissioned

	Mean	Standard Deviation
Institution sells to scrap dealers	1.0	0.65
Recycled	1.0	0.45
Discarded with ordinary trash	4.2	0.58
Kept in the storeroom	4.7	0.47
Sent/Sold to institutions that recycle	1.0	0.35
Reused in less intense processing environments such as computer laboratories	4.0	0.42
I return to the seller/manufacture	2.0	0.55

C. Views regarding the contents of data centre e-waste

Participants were asked about the contents of e-waste, as shown in Table 3; the majority (82%) were aware of the rare earth minerals found in data centre e-waste. Another 76% of the participants were aware of the hazardous elements found in e-waste. Regarding programs and national laws meant to assist in managing and disposing of e-waste, a tenth of the participants were aware of such initiatives and policies. The results are similar to those of Agamuthu et al. [31], who observed that the University of Malaysia had large stockpiles of e-waste due to a lack of disposal procedures, policies, and recycling infrastructure. Participants agreed that improper e-waste disposal was an environmental catastrophe with a mean score of 4.0 and a standard deviation of 0.44. In contrast, a mean score of 3.8 shows that most participants agreed that improper e-waste disposal was an epidemiological disaster. The majority (86%) of the participants agreed that the conservation of natural resources is enhanced through recycling.

Table 3. Knowledge level of e-waste contents and policies

	Mean	Standard Deviation
Are you are of rare earth minerals found in e-waste?	4.1	0.42
Are you aware of hazardous waste chemicals in e-waste?	3.8	0.39
Are you aware of any company that collects or recycles e-waste?	1.0	0.38
Are you aware of any local or national programs aimed at managing e-waste?	1.0	0.38
Are you aware of national that prohibit improper disposal of e-waste?	0.5	0.40
Improper e-waste disposal is an environmental catastrophe.	3.8	0.50
Improper e-waste disposal is an epidemiological disaster.	4.0	0.44
Recycling contributes to the conservation of natural resources	4.3	0.30

D. Measures put in place for proper disposal of data centre e-waste

Participants were asked to highlight the measures taken to dispose of e-waste properly, and their responses are shown in Table 4. The majority (80%) of the participants revealed that they did not have any operational procedures to manage data centre e-waste. Similarly, only 22% of the participants had a data centre e-waste collection program. The lack of e-waste collection programs was cited by Tansel [45] as a hindrance to effective e-waste management. Again, only 28% of the respondents highlighted that they had labelled bins and collection points to minimise their environmental footprint. About three-quarters (74%) of the participants agreed that they had adopted server virtualisation to enhance environmental sustainability by reducing the number of physical servers. About 46% of the participants stored data on the cloud to reduce the number of back-up servers and data storage facilities to reduce their carbon footprint. A few (26%) institutions use the intranet and social media to sensitise and educate staff on e-waste management. Only a tenth of the participants highlighted that they returned their obsolete data centre equipment to the manufacturer or seller.

Table 4. Measures put in place for proper disposal of data centre e-waste

	Mean	Standard Deviation
We have operational procedures	1.0	0.45
We have a collection program	1.1	0.35
We have labelled collection points and bins to ensure the environmental footprint	1.4	0.26
Implemented server virtualisation for environmental sustainability	3.7	0.33
Some of the data is stored in the cloud to reduce the carbon footprint	3.5	0.43
We use the intranet and social media to sensitise and educate staff	1.3	0.30
I return to the seller/manufacturer (Extended Producer Responsibility)	0.5	0.36

E. Data centre location preference

The next question asked participants about their data location preference as an environmental sustainability issue. Participants' responses are provided in Table 5. Results show that most (80%) data centres are onsite for easy accessibility, with 20% located offsite to utilise natural water-based cooling systems. Some (74%) participants had mini data centres as they stored most of their data on the cloud, contributing to green computing and environmental sustainability. Only 44% of the participants indicated they stored most of their data in the cloud.

Table 5. Data centre location preference

	Mean	Standard deviation
Onsite – readily accessible	4.0	0.36
Offsite – use natural cooling systems such as water-based	1.0	0.42
Use a mini data centre as most of my data is on the cloud	3.7	0.56
All my data is on the cloud	2.2	0.31

Participants were asked how often they replaced data centre equipment. As shown in Table 6, 64% replaced after 3-5 years, while the majority (92%) replaced after 6-10 years, and 40% replaced after ten years. Economic factors force institutions to reduce the frequency of replacing data centre equipment, reducing e-waste output.

Table 6. Frequency of replacing data centre equipment

	Mean	Standard deviation
3-5 years	3.2	0.33
6-10 years	4.6	0.29
Over 10 years	2.0	0.44

Participants were asked to provide reasons for replacing data centre equipment, as shown in Table 7; 70% replaced the old equipment with new equipment with better attributes such as functionality and security. Others (88%) were replaced when data centre equipment was no longer usable, while 82% replaced equipment when repairing was no longer economical. These results confirm that most participants adopted environmentally friendly methods that reduce e-waste accumulation.

Table 7. Reasons for replacing data centre equipment

	Population	Standard deviation
Availability of more functionality and security	3.5	0.34
Current equipment is no longer usable	4.4	0.41
When they are more economic benefits of buying instead of repairing	4.1	0.36

The study investigated the awareness of health consequences due to improper disposal of e-waste, as shown in Table 8. The findings show that most (76%) participants knew that e-waste could contaminate water sources and affect aquatic species living in the water. Also, 64% of the participants were aware of dermatological diseases contracted through e-waste exposure. About 62% of the participants agreed that communities living in informal e-waste recycling developed respiratory diseases and affected pregnant women and children. About 58% of the participants also agreed that improper e-waste recycling could destroy grazing land and soil constituents and cause various liver cancers and terminal ailments. Also, 54% of the participants agreed that e-waste exposure could cause neurological disorders. Lastly, about 40% of the participants agreed that e-waste exposure could cause gene and DNA altering and reproductive health complications. Raising awareness of the impact of improper e-waste disposal on human health can help in improving its management. This is supported by Gumbo and Kalegele [46], who highlighted that raising awareness of the health and environmental impact of improper disposal of e-waste can raise awareness and change attitudes.

Table 8. Health consequences due to improper e-waste disposal

	Mean	Standard deviation
Destruction of grazing land and soil constituents	2.9	0.33
Water contamination and threat to aquatic species	3.8	0.40
Dermatological diseases through radiation	3.2	0.29
Development of lung diseases	3.1	0.36
Neurological disorder	2.7	0.42
Cancer of the liver and other terminal ailments	2.9	0.34
Reproductive and estrogenic problems	2.0	0.37
Gene and DNA altering	2.0	0.39
Premature births and pregnancy complications	3.1	0.44

5. Recommendations

There is a need to introduce more e-waste awareness programs to increase knowledge and influence the attitudes of ICT personnel when acquiring and maintaining ICT equipment. More institutions should be encouraged to adopt cloud computing technologies and reduce data centre storage to limit carbon emissions. The absence of national policies on e-waste limits local efforts and enforcement; this study appeals to governments in developing countries to prioritise environmental protection. Therefore, this research raises awareness and knowledge levels regarding the environmental and epidemiological threats of data centre e-waste.

The absence of elementary recycling in the country is worrying, and universities are losing valuable metals that are recoverable from e-waste. The country should facilitate partnerships to encourage the export of e-waste for recycling in developed countries, and this can create employment, generate income and reduce the environmental and health effects caused by indiscriminate recycling by the informal sector. Institutions should have labelled bins to separate data centre e-waste from ordinary garbage to protect the environment from e-waste. Universities should be encouraged to procure equipment from suppliers who can take back used data centre equipment through extended producer responsibility schemes. A small sample was used, which may affect the generalisability of the results. The research only focused on data centre e-waste and did not consider general e-waste.

6. Conclusion

As universities automate most of their operations, they will rely on data centre-driven infrastructure, putting a strain on power consumption and carbon emissions. Developing countries should craft policies that reduce the effects of e-waste on the environment by managing data centre e-waste and increasing awareness. These policies should advocate for purchasing quality products with a longer lifespan. The absence of national policies and operational procedures negatively affects e-waste management as local institutions do not have a blueprint for modelling their operational procedures to manage e-waste. Establishing local policies will raise awareness of the environmental and epidemiological effects of e-waste. University ICT Directors and Managers kept data centre equipment decommissioned in the storeroom while some discarded it with trash. Most participants were aware of dangerous substances and the precious rare earth metals used in ICT manufacture. Most participants redeployed data centre equipment to less intense data processing environments, reducing the e-waste burden.

Regarding the collection of e-waste, only a few institutions labelled bins for collecting e-waste; thus, e-waste is indiscriminately disposed of together with municipal waste. Most institutions virtualised their servers to reduce their carbon footprint by reducing the number of physical servers acquired. This was complemented by almost half of the participants who stored their data on the cloud, reducing the demand for local server infrastructure. Very few institutions practised take-back schemes through extended producer responsibilities; this could be caused by limited suppliers who extended this service to developing countries.

Most institutions located their data centre onsite, citing accessibility but missed benefitting from natural cooling, which lessens the strain on the environment. Data centre equipment was replaced when no longer usable and only when repairing was no longer economic; this reduced e-waste generation and carbon emissions during recycling. Most participants replaced data centre equipment after 6-10 years, thus reducing the replacement frequency and the e-waste burden. Increasing the life cycle of data centre equipment reduces carbon footprint and the frequency of equipment destined for disposal of e-waste. Most respondents were aware of the effect of e-waste on the environment, such as water contamination and the dermatological effects, such as cancers, skin irritations, liver diseases, DNA sequence alterations and hormonal imbalances. Overall, the findings are consistent with several studies on e-waste, such as

Agamuthu et al. [31], Knudsen [44], Oteng-Ababio & Amankwaa [43]; Maphosa and Maphosa [2], who observed that lack of policies constrains e-waste management in most developing countries.

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How to cite this paper: Vusumuzi Maphosa, "Sustainable E-waste Management at Higher Education Institutions’ Data Centres in Zimbabwe", International Journal of Information Engineering and Electronic Business(IJIEEB), Vol.14, No.5, pp. 15-23, 2022. DOI:10.5815/ijieeb.2022.05.02