Sustainable electronic waste management at The University of Kwa-Zulu Natal: Developing an integrated waste management plan using the W.R.O.S.E model.

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Prof. Cristina Trois Date

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DEDICATION

In the memory of the late Kistimal Govender

“1944-2021”

Acknowledgements

"No matter how hard you work, someone else is working harder".

~ Elon Musk (Richest man on earth)

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Abstract

Electronic waste (e-waste) is the fastest growing waste stream in the world and is increasing exponentially, this growth poses a significant problem in the current waste management systems. The current waste management systems, worldwide, are not designed to manage e-waste, and therefore most of the e-waste is mismanaged. E-waste is the most valuable waste stream, as it contains a high concentration of precious metals (as compared to primary minerals), however, it has a significant concentration of toxic material. The mismanagement of e-waste can have disastrous effects on both human health and the environment.

This study focused on improving the e-waste management of the University of Kwa-Zulu Natal (UKZN). UKZN was selected because Universities are considered the frontier for research and development, and often establish higher standards for social responsibility and environmental conservancy than other institutions. The objectives were to firstly investigate the current e-waste management practices, to determine the appropriate strategies that were used to create an integrated waste management plan (IWMP). The required data for the study was obtained using a structured questionnaire, as it allowed for both the qualitative and quantitative data to be collected at once. The questionnaires were distributed across all five campuses and the data was collected.

The analysed data established that UKZN generates a significant volume of e-waste, and the respondents confirmed that UKZN did not have an e-waste management plan and rather e-waste was treated as ordinary waste. Positive feedback from the respondents suggests that they would be accepting of an e-waste management plan.

The IWMP was designed based on the potential volume, composition, and expected quality of the waste stream. The strategies employed were evaluated to ensure economic, environmental, and social sustainability, in both the short term and long term. The IWMP was designed to help create a circular economy and to ensure that e-waste is managed sustainably, and the resources are conserved.

The study concluded by demonstrating that it was possible to manage e-waste sustainably, thereby not endangering either human health or the environment while still being economically feasible.

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Chapter 1: Introduction

This chapter serves as an overview of the study. In this chapter, the study's background, research problem, aims, objectives and methodological approach are discussed. This is proceeded by the significance and limitations of the study. This chapter concludes by highlighting the structure of the dissertation.

1.1 Background to the study

According to Blade. Et.al (2017) the rapid generation of electronic waste has led to significant waste management and environmental problems worldwide. According to the United Nations University and Step initiative (2014), electronic waste (e-waste) is a term used to cover all types of electrical and electronic equipment (EEE) and its parts that have been discarded by the owner as waste without the intention of reuse. Most of the electronic waste originates from homes, government organisations, and private companies (Ilankoon, et al., 2018).

According to the Global e-waste monitor (2017), in 2014, approximately 41.8 million tons of e-waste was generated. This figure increased to 52 million tons in 2020; this represents a 5 % increase per annum (Global E-waste monitor, 2017). According to Blade et al. (2017), the developed countries generated most of the global e-waste. The global leaders are the European Union member states (9.5 million tons a year) followed by the United States (7 Million tons a year) (Bladé, et al., 2017). Many developed countries export most of their e-waste to developing countries (transboundary movement) as a cost-effective method of e-waste disposal, while the developing countries see this as an opportunity to access low-cost electronic devices (Step Initiative, 2014). South Africa generates the most considerable quantity of electronic waste (350 kilotons) on the African continent, with an expected increase of 5-7% year on year increase.

According to Ilankoon, et al. (2018) e-waste is the fastest growing waste stream and is a problem for current and future waste management. The rapid development of the Internet has seen the connection between the virtual and physical world getting stronger as technology and infrastructure improve (Lawhon, 2013). According to the Global e-waste monitor (2017), the rapid development of mass manufacturing of electronic devices has made access to these devices more economical.

According to Forti, et al. (2018) these more economical electronic devices have seen the average global consumer owning more electronic devices year on year. This, in turn, provoked a sharp spike in the number of electronic devices entering developing countries (Lawhon, 2013). It is not just consumer electronics that have increased in developing countries; many institutions have also upgraded their analogous methods to more digital solutions (Forti. et al., 2018). The increase in electronic devices used, directly correlates with the amount of e-waste generated (Global e-waste monitor, 2017).

Globally most of the e-waste generated is disposed into landfills, as electronic waste is commonly mixed in with the Municipal waste stream (MWS) (Kaya,2019). The disposal of e-waste in the MWS is perceived as the most convenient method for consumers to dispose of e-waste, as it requires little effort. According to Perkins, et al. (2014) when electronic waste is disposed of in the municipal waste stream, it has adverse effects on the environment and human health; many precious metals that are present in most of electronic devices such as copper and aluminium, are, therefore, lost.

According to Machete (2017), the current waste management system in South Africa is not designed to process and treat e-waste in a safe and sustainable manner. Instead, most e-waste is treated as regular municipal waste and disposed into a landfill. According to STEP (2014), e-waste should not be disposed into landfill sites, since e-waste contains a significant amount of toxic material that has adverse effects on human health and the environment.

National authorities have illustrated that a more circular economy must be adopted by society (Ellen Macarthur foundation, 2015). A circular economy is an ecosystem that is centred around continually using waste as a resource, as a method of eliminating waste.

1.2 Research problem

South Africa generates the largest volume of e-waste in the African continent over 350 000 tons a year in 2014 and this has increased to 500 000 tons in 2020, this represents a 5% year on year increase (Global e-waste monitor, 2017; Ichikowitz, 2020). The South African electronic waste landscape is complex and economically diverse as approximately 20% of the South African population consumes 50% of the national resources (Grant & Oteng-ababio, 2012).

According to Anderson (2019), in South Africa, there has been a continuous increase in demand of consumer, industrial and commercial electronic devices from the early 2000s. In South Africa, the rapid increase in industrialisation and urbanisation from the early 2000s, has seen a significant portion of the population increasing their disposal income (Anderson, 2019).

According to Arain et al. (2020), higher educational institutions have seen rapid digitalisation, moving away from traditional teaching methods to computer-based. According to Forti. et al. (2018) educational facilities in developing countries (such as in South Africa) have rapidly increased their dependence on computer-based learning. A study by Ledwaba & Sosibo (2017), stated an average South African university has approximately one desktop computer available for every six students (in 2016) compared to 2004 when it was only one desktop computer for every twenty-four students. The above demonstrates an apparent increase in the use of electronic devices by educational facilities, and these devices will either break or become obsolete and become e-waste.

In South Africa, there is an urgent waste management problem, as most landfills are nearing capacity, and landfill space is becoming scarce (Khumalo, 2018). In the KwaZulu-Natal province, this problem is severe, and the eThekwini Municipality (the largest municipality in KwaZulu Natal) has also realised that a responsible approach to waste management must be taken. The eThekwini Municipality intends to create more opportunities for the recycling of waste by implementing an Integrated Waste Management Plan (IWMP) centred on sustainable waste management (eThekwini Municipality, 2013).

The University of KwaZulu Natal, in response to the eThekwini municipality's call for sustainable waste management, is developing an integrated waste management plan in the hope of creating a more circular economy (Shriram, 2018). According to Shriram (2018), the programme is called Green-UKZN, and the aim is to promote waste minimisation by emphasising the reuse and recycling of waste.

The Green UKZN programme has identified many solid waste sources that it will minimise, such as food waste, garden refuse and paper waste (Shriram, 2018). However, at the time of writing, e-waste is not identified as a source of waste included in the Green UKZN programme; therefore, this study examined how the sustainable management of electronic waste can be undertaken at the University of KwaZulu Natal.

1.3 Aim and objectives of the study

The study's proposed aim is to aid the University of Kwa-Zulu Natal in improving the current waste management strategy to accommodate electronic waste in a sustainable manner. The aim was systematically broken down to create the objectives of the study that are as follows:

- To determine the electronic waste stream at UKZN, (by means of a study).
- To investigate the current e-waste management practices at UKZN.
- The develop an Integrated Waste Management Plan (IWMP) using the W.R.O.S.E model, a replicable model for sustainable e-waste management at university campuses across South Africa.

1.4 Significance of the study

The study of e-waste is essential, as e-waste is the fastest growing waste stream globally; hence the volume of e-waste worldwide is ever-increasing (Global e-waste monitor, 2017). According to Borthakur, et al. (2012) e-waste is a concerning problem, as it is not safe to dispose of in a landfill site like a regular municipal waste. E-waste contains toxic material (heavy metals such as lead, chromium and mercury), which can adversely impact both human health and the environment (Borthakur, et al., 2012).

In developing countries, particularly African countries, e-waste is a particular problem as the growing economies have seen an influx in demand for electronic and electrical equipment, primarily due to the increase in disposable incomes, as now more consumers have the means to access electronics (Lawhon, 2013). According to Amuzu (2018), the increased demand for electronics and electrical equipment strongly correlates with an increase in e-waste, as more electronic devices are consumed, more e-waste will be generated.

South Africa has one of the largest economies in Africa, in 2014 South Africa generated 346 metric kilotons of e-waste, the largest volume in Africa. This volume of e-waste is predicted to increase between 5-7% each year (Global e-waste monitor, 2017). According to Ledwaba & Sosibo (2017), in recent times the most significant volumes of e-waste can be generated from industrialised areas such as office parks (offices buildings), educational facilities (Universities and trade schools) and the residential regions (Homes and building complexes).

Educational institutions such as the University of KwaZulu Natal pose a significant threat, as there are multiple sources of e-waste from these institutions. The most common sources of e-waste originate from the campus facilities (Computer laboratories, lecture venues and offices), external stores (i.e., printing shops) and personal e-waste (phones, laptops and charging equipment).

Upon reviewing past published literature, the previous studies regarding waste management (Zero waste and the Green UKZN project) at the University of KwaZulu natal (UKZN) had not considered e-waste.

This study is a comprehensive study of e-waste at an educational facility (UKZN), i.e., estimating the volume of e-waste generated, investigating current e-waste management practices, analysing social behaviours, and evaluating environmental impacts. A study of this nature has not taken place at UKZN, and the findings have been used to expose the shortcomings and deficiencies currently experienced.

The study will use the W.R.O.S.E model to help create an integrated waste the management plan to help produce better waste management practices. The use of the W.R.O.S.E model for management of e-waste has not been undertaken before, and this study will evaluate its suitability for such a waste stream. The results of this research will demonstrate the flexibility of the W.R.O.S.E model, illustrating its potential uses.

At present, there is no authorised e-waste management strategy in South Africa, and most of the e-waste is disposed into either a landfill or a dumpsite (Lawhon, 2013). The findings of this study will be impactful as it will provide insights and strategies for sustainable e-waste management, which could help decision-makers in various organisations and institutes create and implement an e-waste management plan.

1.5 Methodological Approach

The study was designed to quantify the potential e-waste volume and determine the current e-waste management practices of the five campuses of the University of KwaZulu Natal (UKZN). Upon determining the above, an integrated waste management plan (IWMP) was created to manage e-waste at UKZN sustainably. The IWMP was designed using the W.R.O.S.E model.

This study adopted the W.R.O.S.E model as its decision-making tool in the design of the IWMP, as the W.R.O.S.E model is a holistic method of analysis that includes sustainability indicators (Economic, social, and environmental) and has been used in many previous studies in South Africa (Trois & Kissoon, 2020). The W.R.O.S.E model used a combination of different strategies to create a variety of waste management scenarios that were evaluated based on the current study. The following scenarios are based on the scenarios suggested by Trois and Kissoon (2016) and adapted for the management of e-waste:

- Scenario 1: unsorted e-waste in the combined waste stream is collected by a contractor and is to be directly disposed of in a landfill.
- Scenario 2: unsorted e-waste in the combined waste stream is collected by a contractor, the contractor separates e-waste from the stream and sells it to a recycling agent.
- Scenario 3: source-separated e-waste, is sold to the contractor. The contractor refurbishes the functioning electronics and sells to a resale agent. The contractor sells the non-functioning electronics to a recycler.
- Scenario 4: source-separated e-waste. The functioning e-waste is to be refurbished by UKZN and be reused internally or by another government agent. The non-functioning e-waste is to be sold by the contractor to a recycling agent.

The research questionnaire was designed based on the required data for the W.R.O.S.E model. The primary data required is the volume of e-waste, the average life of electronic and the quality of the e-waste; this information was required to determine the specific strategy to be implemented. The secondary data required was the awareness of participants to any e-waste management plan and the environmental and social impacts of e-waste management. This information was used to determine the sustainability of the selected strategy.

The data was collected through a structured questionnaire; the questionnaire was selected because it can gather quantitative (i.e., the volume of e-waste) and qualitative (i.e., attitudes toward e-waste management) data. The questionnaires were administered to the respective representatives of UKZN, during the first half of 2020 (between February and May).

The research sample was comprised of selected areas within the UKZN campuses that had the most e-waste volumes, i.e., the computer laboratories, office areas, and lecture venues.

Each campus had a total of 200 of the above facilities, this translates to all five campuses having 1000 facilities in total, therefore according to Sekaran and Bougie (2014) the appropriate sample size for this target population is 278.

However, due to many government restrictions enforced due to the Covid-19 global pandemic, the sample size had to be limited. The sample size was limited to only computer laboratories, as these facilities were regarded as priority facilities and remained open. In compliance with government restrictions concerning the pandemic, most of the questionnaires were administered through email, as the researcher attempted to limit "person to person" contact as much as possible. The altered sample consisted of 90 computer facilities, the results from the computer laboratory are still satisfactory to draw conclusions as most of the e-waste originates from these facilities (90% of e-waste).

The expected e-waste stream of an educational institution such as UKZN is primarily dominated by learning aids and tools such as desktop computers, printers, and projectors. However, there is also a minority of other e-waste such as lighting equipment's, switches, and fixtures. The data collected was processed in the W.R.O.S.E, and the respective scenarios were evaluated. The optimal short and long-term solution was determined and evaluated for economic, social, and environmental sustainability. The selected scenarios were then used to create an IWMP for UKZN.

1.6 Limitations of the study

The limitations of the study are shown below:

- The sample was limited to the University of KwaZulu Natal, and other universities were not able to be tested (Such as Durban university of technology (DUT) and Varsity College (VC)).
- The conclusions derived from the study are to be obtained solely from the responses; therefore, the research's reliability is dependent mainly on the respondents.
- Respondents can incorrectly answer questions due to misunderstanding or confidentiality concerns. The participant's responses can be influenced by factors such as the ability to understand the questions; the degree of honesty when answering the questionnaire; time to answer the questionnaire and general attitude to answering questionnaires.

- Due to the Covid-19 global pandemic, the government imposed numerous sanctions that limited the movement and interaction of people. Therefore, the number of questionnaires distributed was limited to only the computer laboratories. Computer laboratories remained open, as it was classified as an essential service, while offices and lecture venues were closed. These restrictions limited the sample size and the overall number of respondents.

1.7 Structure of the dissertation

The dissertation is divided; into seven chapters:

Chapter 1: Introduction/Overview of the study

Chapter one provides a brief background into the study, identifies the research problem and states the aims and objectives of the study. The structure of the research is briefly outlined. The significance of the study is also discussed.

Chapter 2: A literature review

In this chapter, the management of electronic waste, both domestically and globally, were reviewed. The sources and hazardous nature of electronic waste are explored. The factors influencing the generation of the electronic waste composition of the electronic waste stream are inspected. The review covered electronic waste legislation, the social and environmental impact, and the economic benefit of recycling electronic waste.

Chapter 3: Research methodology and design

This chapter focuses on the research methodology employed for this study. It includes discussing the research design, the research instrument, data collection methods, data analysis techniques, and the methods used to ensure that the research is valid and reliable.

Chapter 4: Pilot study

The pilot study of the research questionnaire will be undertaken to assist in detecting any ambiguous questions, assess the time taken to fill in the questionnaire and determine if it was aligned to the study's objectives and literature reviewed.

Chapter 5: Presentation of the results

The results obtained from the questionnaire were analysed and presented (descriptively) using graphs, charts, and tables.

Chapter 6: The integrated waste management plan (IWMP)

Based on the data obtained from chapter 6, the IWMP will be created to manage e-waste economically feasible, socially sustainable, and economically sustainable.

Chapter 7: Review, Conclusion, and recommendations

This chapter contains a summary of the key findings of the study and makes recommendations for further research. The chapter concludes by elaborating the sustainable practices that can be undertaken at the University of KwaZulu natal (UKZN) Howard campus.

1.8 Conclusion

This chapter served as a guide to the research undertaken at the University of Kwa-Zulu natal. The study's background, the problem statement, and the aim and objectives of the study are outlined. The significance of the research and the research methodology was discussed. In the following chapter, the review of the literature regarding electronic waste management is elaborated and discussed.

Chapter 2: Literature Review

2.1 Introduction

In this chapter, the review of literature relating to electronic waste is presented and evaluated. The literature review will create the context of the problem and validate the researcher's approaches in various study stages.

The literature review will encompass the definition of electronic waste, the source from which electronic waste originates, the current and future volume of electronic waste generated from a global context to a local South African context. The drivers that influence electronic waste generation will be reviewed in terms of economic growth and consumerism. The literature review concludes by evaluating how the circular economy influences sustainable development and how integrated waste management will create a circular economy.

2.2 Definition of electronic waste

There are many definitions of electronic waste; however, there is no single definition that is unanimously accepted. An extensive literary study was undertaken to determine a relevant definition for this research study. Some of the definition that was considered include:

- An electrically powered appliance that no longer satisfies the current owner for its original purpose (Khetriwal et al., 2016);
- Any discarded appliances using electricity, which includes a wide range of e-products from large household devices such as refrigerators, air conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users (BAN, 2013);
- e-waste refers to any white goods, consumer and business electronics, and information technology hardware that is at the end of its useful life (Khurrum & Bhutta, 2011);
- E-waste refers to the reverse supply chain that collects products no longer desired by a given consumer and refurbishes for other consumers, recycles, or otherwise processes wastes (Step Initiative, 2014);

- E-waste is the term used to describe old, end-of-life electronic appliances such as computers, laptops, televisions, DVD players, cellular phones and MP3 players. which have been disposed of by their original users (Electronic take back coalition, 2014);
- anything that works with electricity or batteries, and it is no longer needed, or it is no longer working, is classified as e-waste (E-waste Africa, 2015).
- The definition that is to be used in this study is the definition used by the United nation's university (2015) and is as follows: “e-waste is a term used to cover items of all types of electrical and electronic equipment (EEE) and its parts that the owner has discarded as waste without the intention of re-use”.

2.3 The sources and classification of electronic waste

The purpose of identifying and classifying sources of electronic waste is that it assists the estimation of the total electronic waste generated. The type of electronic waste stream is to be evaluated to determine if electronic devices are reusable or waste; this subchapter will explore these ideas.

2.3.1 Source of electronic waste

Electronic waste can originate from many sources and at various stages of its life cycle (Forti et al., 2018). The most common sources of e-waste originate from:

- Waste from the manufacturing of electronic products.
- Redundant electrical and electronic equipment discarded by repair shops.
- Obsolete electronic equipment from various public and private organisations and
- Obsolete electrical or electronic products from households.

A study conducted by Kaya (2019) studied the most common source of electronic waste to determine the average mass and estimated life span of electrical and electronic devices. The study used this data to determine the potential electronic waste in the study area. The study also noted that when determining the potential electronic waste, it can only be done for a finite period (i.e., the amount of electronic waste generated in a 5-year period). The study results, the possible electronic equipment that generates electronic waste and the respective mass and lifespan, can be shown in table 2.1.

Table 2.1: Source of e-waste, their approximate mass and life span (Forti, et al., 2018; Kaya, 2019).

Type of electronic item	Mass (kg)	Estimated life span (years)
Air conditioner	55	12
Cellular phone	0.1	2
Dish washer	50	10
Electric cooker	60	10
Electronic game consoles	3	5
Facsimile machine	3	5
Food mixer	1	5
Freezer	35	10
Hairdryer	1	10
High-fidelity system	10	10
Iron	1	10
Kettle	1	3
Microwave	15	7
Personal Computer	25	7-8
Photocopier	60	8
Projector	10	10
Refrigerator	35	10
Telephone	1	5
Television	30	5
Toaster	1	5
Tumble Dryer	35	10
Vacuum cleaner	10	10
Video recorder/DVD Player	5	5
Washing machine	65	8

See appendix A (Table A3), for the full list of the sources of e-waste.

2.3.2 Classification of electronic waste

According to the European Parliament and The Council of the European Union (2012), the data from table 2.1 can be categorised into 10 classes (also shown in appendix A, Table A1). The electronic waste categorisation is required because over 100 000 different electrical and electronic devices and when placed into classes, can assist in various analysis methods (Appendix A, Table A2). The various classes of waste from electrical and electronic equipment (WEEE) can be classified in the following categories, as shown in table 2.2:

Table 2.2: UNU EU-10 Classification (Global E-waste monitor, 2017; Bladé, et al., 2017)

Class	Category	Examples
1	Large household appliances	Refrigerators, stoves, etc.
2	Small household appliances	Toasters, irons, etc.
3	IT and telecommunications equipment	Desktop computers, laptops, cellular telephones, etc.
4	Consumer equipment and photovoltaic panels	Televisions, hi-fi's, musical instruments, etc.
5	Lighting equipment	Globes, electric lamps, etc.
6	Electrical and electronic tools	including control boards and large-scale stationary industrial tools
7	Toys, leisure, and sports equipment	video games, remove controlled toys, etc.
8	Medical devices	radiotherapy equipment, cardiology equipment, nuclear medicine equipment, etc,
9	Monitoring and control instruments	electronic control desks, screens, etc.
10	Automatic dispensers	vending machines, automatic teller machines, etc.

According to Tansel (2017), one of the more frequent sources of e-waste is the personal computer/Laptop, followed by mobile devices and televisions equipment. According to Govender (2016), in 1975, less than 50 000 computers, valued at approximately $60 million, were sold. However, in 2010, over 320 million personal computers, with a retail value of approximately $320 billion, were sold, and it is estimated that approximately 2.1 billion personal computers will be sold by the end of 2015 (Govender, 2016).

2.3.3 Type of electronic waste streams

In 2014 the Basel convention published some technical guidelines to assess the functionality factors that contribute to the progressive growth of e-waste. These factors are the rising consumption of electronic and electrical equipment (EEE), increasingly rapid obsolescence (due to sustained technological advances) of electronic devices, and the decreasing product lifespan (shown in Appendix A. table A4) and potential reuse of electronic devices (Wordloop, 2013; Kusch & Hills, 2017).

According to Perkins et al. (2014), the importance of adequately classifying e-Waste is to determine which electronic can still be used and which must be treated as waste. This information can then be used to aid the estimation of e-waste quantities further. The guidelines' primary objective was to classify the quality of electronics entering the second-hand market (primarily in third world countries). A summary of the technical guidelines is shown in table 2.3.

Table 2.3: Classifying the Multiple Types of E-waste (Perkins, et al., 2014; BAN, 2013)

Type of stream	Description	Classification
New and functioning EEE	New products or components being delivered and shipped between different countries.	This stream is classified as “non-waste” by default, (new products for distribution).
Used and functioning EEE suitable for direct reuse	The equipment needs no further repair, refurbishment, or hardware upgrading.	This stream can be classified as “non-waste”; however, in some country’s export/import restrictions apply.
Used and non-functioning but repairable EEE	Equipment that can be repaired, returning it to a working condition performing the essential functions, it was designed for. Testing is required to determine this condition.	Classification of this stream is under discussion by Basel Parties, as the repair process may result in hazardous parts being removed in the country of repair, thus possibly resulting in transboundary movement of hazardous waste. Some countries would classify this stream as “waste”; others classify it as “non-waste”.

Used and non-functioning and non-repairable EEE	The common form of "e-waste." Can be mislabelled as "used EEE."	Should be classified as "waste".
WEEE	EEE that is waste within the meaning of the Waste Framework Directive context, including components and subassemblies.	Should be classified as "waste".

The classification of electronic waste (as shown in table 2.3), when used in conjunction with the Basel convention's technical guidelines (as shown in table 2.2), can be used to identify electronic waste. The average quantity of electronic waste is estimated using the average weight (Appendix A, Table A3) and the average lifespan (Appendix A, Table A4). The evaluation of electronic waste generation will be conducted in the following chapters.

2.4 The volumes of electronic waste generated.

In this subchapter, the current global quantities of electronic waste will be illustrated, and the potential future generation of electronic waste. The transboundary movement of electronic waste will be discussed and how It impacts developing countries.

2.4.1. Global electronic waste generation

According to statistical analysis performed by The Global e-waste monitor (2017), in 2014, approximately 41.8 million tons of e-waste was generated worldwide. According to Ilankoon et al. (2018), the year-to-year generation of electronic waste increases at a rate of 3-5% globally (Ilankoon et al., 2018). The rate at which electronic waste generation is increasing makes it the fastest growing waste stream (Ilankoon et al., 2018). According to the global e-waste monitor (2017), if a 5% year on year increase is maintained, as shown in figure 2.1, in 2020, approximately 52 million tons of electronic waste will be generated.

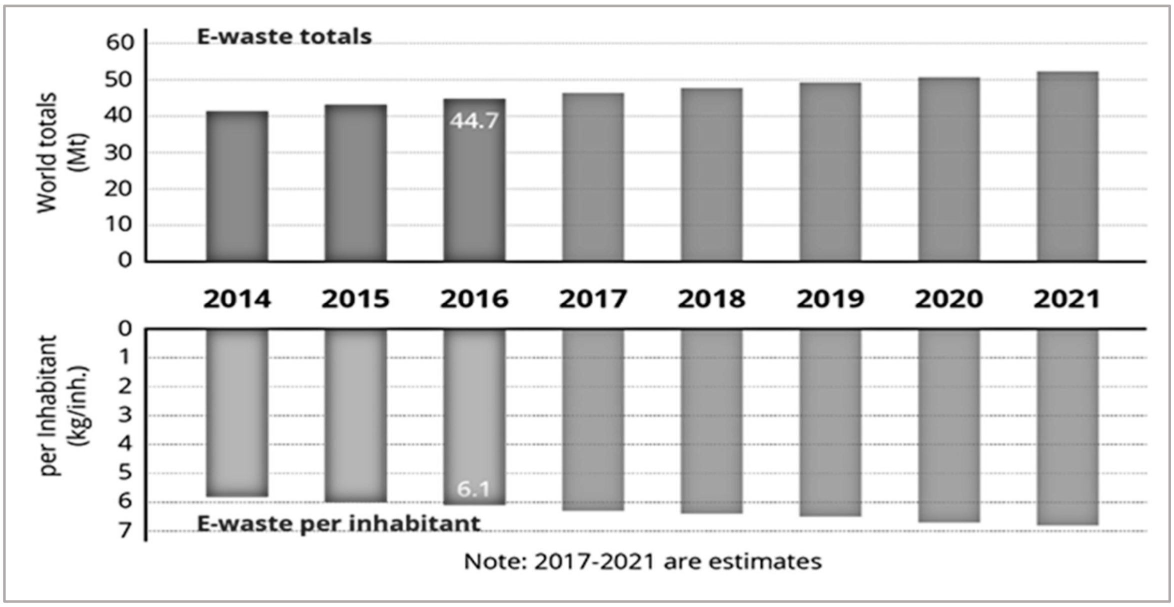


Figure 2.1: The E-waste generation rates (Global E-waste monitor, 2017)

A study by Blade. Et.al (2017) concluded that in 2014 the countries in the European union generated 9.5 million tons of e-waste which is more than 20 % of the global tally, followed by the United States of America (7 million) and China (6 million). In the same study, Blade. Et.al (2017) stated that the entire African continent generated less than 3 million tonnes, with South Africa generating the most significant volumes (0.35 million tonnes). In table 2.4, the total electronic waste produced is illustrated and the waste generated per person.

Table 2.4: Global and selected country electronic waste production (Step Initiative, 2014; Global E-waste monitor, 2017; Bladé, et al., 2017; The Global E-waste-Statistics partnership, 2018).

Country/Region	Per Capita Production (Kg).	Total e-waste Production in 2014 (Million tonnes)
World (2014)	5.9	41.8
World (2016 Projected data)	6.1	44.7
World (2020 Projected data)	6.8	52.2
United Kingdom	23.5	1.5
USA	22.1	7.0
Germany	21.7	1.77
Hong Kong	21.5	0.16
Canada	20.4	0.72
Australia	20.1	0.46
Singapore	19.6	0.11
European Union	18.7	9.5
Taiwan	18.6	0.44
Japan	17.3	2.2
South Korea	15.9	0.8
Malaysia	7.6	0.23
Brazil	7.0	1.40
Argentina	7.0	0.29
South Africa	6.6	0.35
China	4.4	6.0
Sri Lanka	4.2	0.09
India	1.3	1.6
Nigeria	1.3	0.22
Zambia	0.9	0.01

2.4.2 The transboundary movement of electronic waste.

According to the Step initiative (2014), developed countries such as the United States and those found in the European Union tend to export much of their generated waste to developing parts of the world, such as Africa, East Asia, and China. In 2014, the United States exported approximately 50-70 % (4-5 million tonnes) of electronic waste to developing countries, such as China (approximately 60%), India, Nigeria, and Ghana (Passafaro, 2016).

According to the United nation's university (2015), the European Union, funded a project in 2012 investigating the illegal trade of waste electrical and electronic waste, which The United

Nation's University undertook. The project found that in Europe, only 35% (3.3 million tonnes) of all electronic waste was properly recycled by authorised agents (United Nations University, 2015). The other 65 % (6.2 million tonnes) was either exported or disposed of in an unauthorised manner (Landfilling or informal recycling) (United Nations University, 2015).

The main reason for exporting to developing countries is the cheap labour and relaxed legislation; it becomes a more convenient method of handling the problem (Borthakur et al., 2012). Therefore, there is a disparity when reading these statistics, and careful considerations must occur when creating a waste management plan.

A study conducted by Orlins and Guan (2016) illustrated that developing countries, such as India and China, have been importing e-waste and salvaging second-hand electronics as a cost-effective method of obtaining electronics. However, in recent times these developing countries have grown economically and have set strong legislation to prevent e-waste from entering these countries; however, there have not been any significant changes, and electronics are still entering these countries (Zeng et al., 2016).

2.4.3 African electronic waste scenario

According to Lawhon (2013), the vibrant growing economies in Africa have seen a demand for electronic and electrical equipment, primarily due to increased disposable incomes. Consumers now have the means to access electronics. The demand for these electronic accompanied by relaxed legislations has led to developed countries using developing countries, such as the African countries of Ghana, Nigeria, and Kenya, as dumping grounds for their electronic waste (Kamel, 2013).

A study conducted by Otsuka et al. (2012) discovers that Ghana is one of Africa's largest importers of e-waste, with approximately 500 containers (or 1000 tonnes) of electronic waste being imported into Ghana every month. In Ghana, the city of Agbogbloshie has experienced the impacts of electronic waste dumping, with hundreds if not thousands of monitors and other electronics being dumped and informally processed there daily (Oteng-ababio, 2012). Many developed countries have taken advantage of Ghana's limited resources to track and detect the import of e-waste (Caravanos et al., 2011; Otsuka et al., 2012).

According to Wenwanne (2019), in 2015, Nigeria saw 56,000 tonnes of imported e-waste; in 2017, this figure increased by more than four times to 288,000 tonnes in 2017. Nigeria has a weak port regulation system, which paves the way for the illegal import of second-hand or refurbished electronics without confirmatory testing to check if they are still usable (Caravanos et al., 2011; Nnorom & Osibanjo, 2008). This imported waste presents a wide network of economic opportunities for importers, scavengers on landfills, and recyclers, despite the risks posed to human health by the materials when incorrectly disposed of. As a result, the illegal activity becomes more attractive and more difficult to stop (Oteng-ababio, 2012).

The Basel Convention has set up "Basel Convention Regional Centres" (BCRC) (namely, Egypt, Nigeria, Senegal, and South Africa) to assist countries in Africa, combat the transboundary movement of electronic waste into these countries and the illegal dumping of hazardous materials (Basel Action Network, 2008). They aim to deliver training, disseminate information, consult on electronic waste matters, raise awareness and engage in technology transfer on matters relevant to The Basel Convention, and ensure that organisations practise environmentally sound management procedures of hazardous and other waste (Basel Action Network, 2008). (Basel Action Network, 2008).

2.4.4 South African electronic waste scenario

According to Ledwaba and Sosibo (2017) research, South Africa is a developing country that generates electronic waste at the rate of a developed country; in 2014, South Africa produced 346 metric kilotons (0.346 million tonnes), a rate of 6.6 kg per inhabitant. If the current rate of electronic consumption is continued (5-7 %), South Africa can potentially generate over 500 metric kilotons (or 0.5 million tonnes) by 2020 (Ledwaba & Sosibo, 2017).

The South African electronic waste landscape is complex and economically diverse as approximately 20 % of the South African population consumes 50% of the national resources (Grant & Oteng-ababio, 2012).

A significant portion of the South African population use second-hand electronics and electrical devices, as it is economically more feasible (GreenCape, 2019). According to Amuzu (2018), the disguise of electronic waste as second goods is a method widely used to move the electronic waste from the urban areas to the more rural areas as a disposal method.

The current South African waste management system is not designed to include electronic waste; therefore, most electronic waste recycling is done by the private sector (Amuzu, 2018).

The formal recycling industry in South Africa is growing as electronic waste's economic value is being realised. There is a significant portion (approximately 20%) of electronic waste being recycled informally; the lack of training exposes these recyclers to the harmful material in electronic waste (Fin24, 2015).

2.4.5 Electronic waste at higher education institutes

According to the International Journal of Scientometrics, info metrics and bibliometrics (2014), there are approximately 17 036 higher education institutes and universities worldwide (IJSIB, 2014). According to Agamuthu et al. (2015), institutions such as universities have the potential to contribute significantly to the rapidly growing threat of e-waste. Information and communication technology (ICT) equipment (such as desktop and laptop computers, printers and photocopy machines) are the most widely used and most frequently replaced electronics in universities. Therefore, the bulk of e-waste generated in universities is from ICT equipment (Agamuthu et al., 2015).

Abraka, Nigeria, established a lack of efficiency in managing ICT e-waste at the institution. This problem was the lack of understanding and policy related to e-waste management (Ogbomo et al., 2012). A study by Arain et al. (2020) investigated e-waste management at The University of Michigan in the United States. A survey was administered to faculty, graduate students, undergraduate students, and staff to determine their personal e-waste management habits, knowledge, and beliefs of safe e-waste management.

The same study by Arain et al. (2020) concluded that cost and convenience are the most critical factors to the study's consumers when deciding whether to recycle e-waste formally or not. Secondly, the study illustrated that consumers have a poor knowledge of what e-waste is and where it can be disposed of. Finally, despite the majority of respondents stating that they considered the sustainable disposal of e-waste ‘‘extremely important”, nearly half reported never recycling e-waste through formal methods (Arain et al., 2020).

The study was undertaken by Chibunna et al. (2012) at the University of Kebangsaan Malaysia (UKM), in which the current e-waste management of the institution was evaluated. The research was conducted on both the employees and students and was designed to estimate the potential e-waste and understand the current awareness of sustainable e-waste management (Chibunna et al., 2012). There are over 8000 desktop computers, 300 printers and 250 projectors in UKM, and all of these electronic will become e-waste in the next 5-7 years. The study concluded that the awareness of e-waste management among UKM is still low. This indicates the low level of awareness on e-waste at the municipal level as assumed each of these respondents represents a household within the municipality.

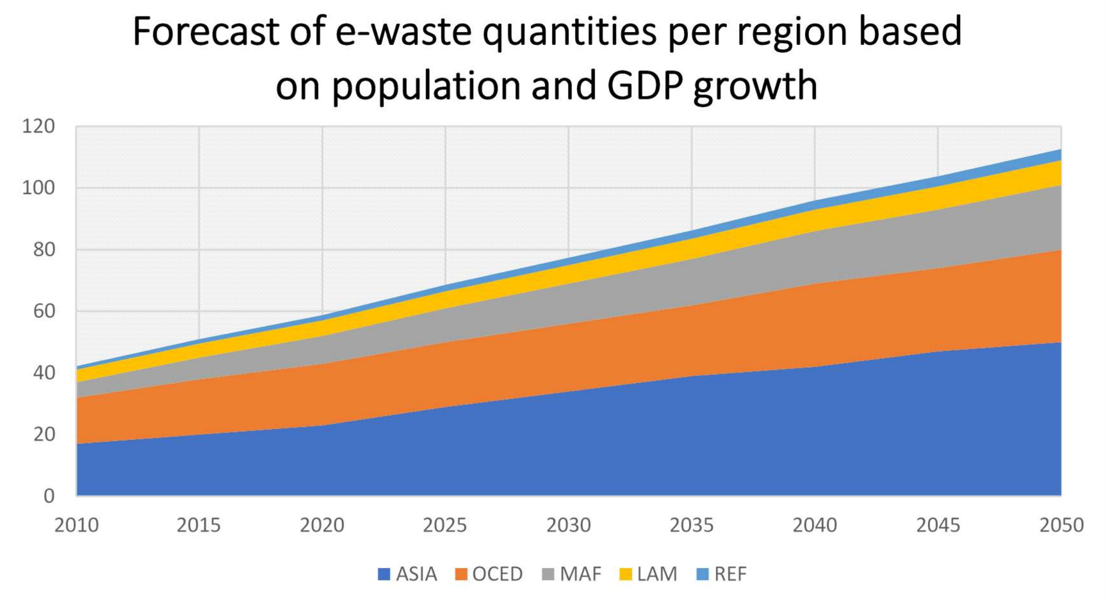
A study by Bonhomme et al. (2012), investigated the potential e-waste generation; in the University of Sao Paulo (USP), USP is the largest higher education institution in Brazil and has seven campuses. The University comprises 80,000 students, faculty, and staff. The University also has an arsenal of 37,420 desktop computers, 15,593 printers, and 3,998 network hardware in use at any given time, and each year, approximately 20% of these equipment's will become obsolete in the next year (Bonhomme et al., 2012).

2.5. Future electronic waste landscape

In this subchapter, the discussion of how the volume of electronic waste will develop in the future. The drivers that influence the change in future volumes will be presented and discussed.

2.5.1. Future electronic waste trends

A study conducted by Parajuly et al. (2019), estimated that in the year 2050 there would be approximately 110 million tons (as shown in figure 2.2) of electronic waste will be generated annually around the world. The most significant contributors will be Asian countries (such as India and China) that will generate approximately 40 million tons, just less than half of the total global electronic waste generated. The African countries will rapidly grow in the future and contribute approximately 26 million tons which is approximately 9 times as much as the continent generates. The electronic waste problem is quickly growing and therefore, the necessary measure must be put into place.



ASIA	Asian countries with the exception of the Middle East, Japan and Former Soviet Union states
OCED	OECD 90 and EU member states and candidates
MAF	countries of the Middle East and Africa
LAM	countries of Latin America and the Caribbean
REF	countries from the Reforming Economies of Eastern Europe and the Former Soviet Union

Figure 2.2: Forecast of e-waste quantities per region based on population and GDP growth (Parajuly, et al., 2019)

2.5.2 Sector based growth: The internet of things domain tree (Iot's)

The term "internet of things (IoT)" is often used to describe the connection between the digital and physical world. The formal definition used is:

"*A global infrastructure for the information society enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving information and communication technologies*" (Cosmas, 2015).

The connection between the virtual and physical world is getting stronger as technology and infrastructure improvements as we continue to solve our real-life problems with digital solutions (Botta et al., 2015). A study conducted by Tanweer (2018) concluded that by 2020 at least 30.73 billion electronic devices would be connected, and by 2025, at least 75.44 billion, and this trend will continue in the future. As we see more electronic devices being connected, we will see more becoming obsolete, increasing the annual e-waste generated. The boom of the internet will see many sectors moving away from physical towards more digital solutions (Henrisson & Rivera, 2014). The sectors that will be discussed in more detail are wireless technology, energy, education, healthcare, security and the creation of smart cities (see figure 2.3). These areas are mostly to see the greatest adoption of IoT solutions and generate the most amount of electronic waste.

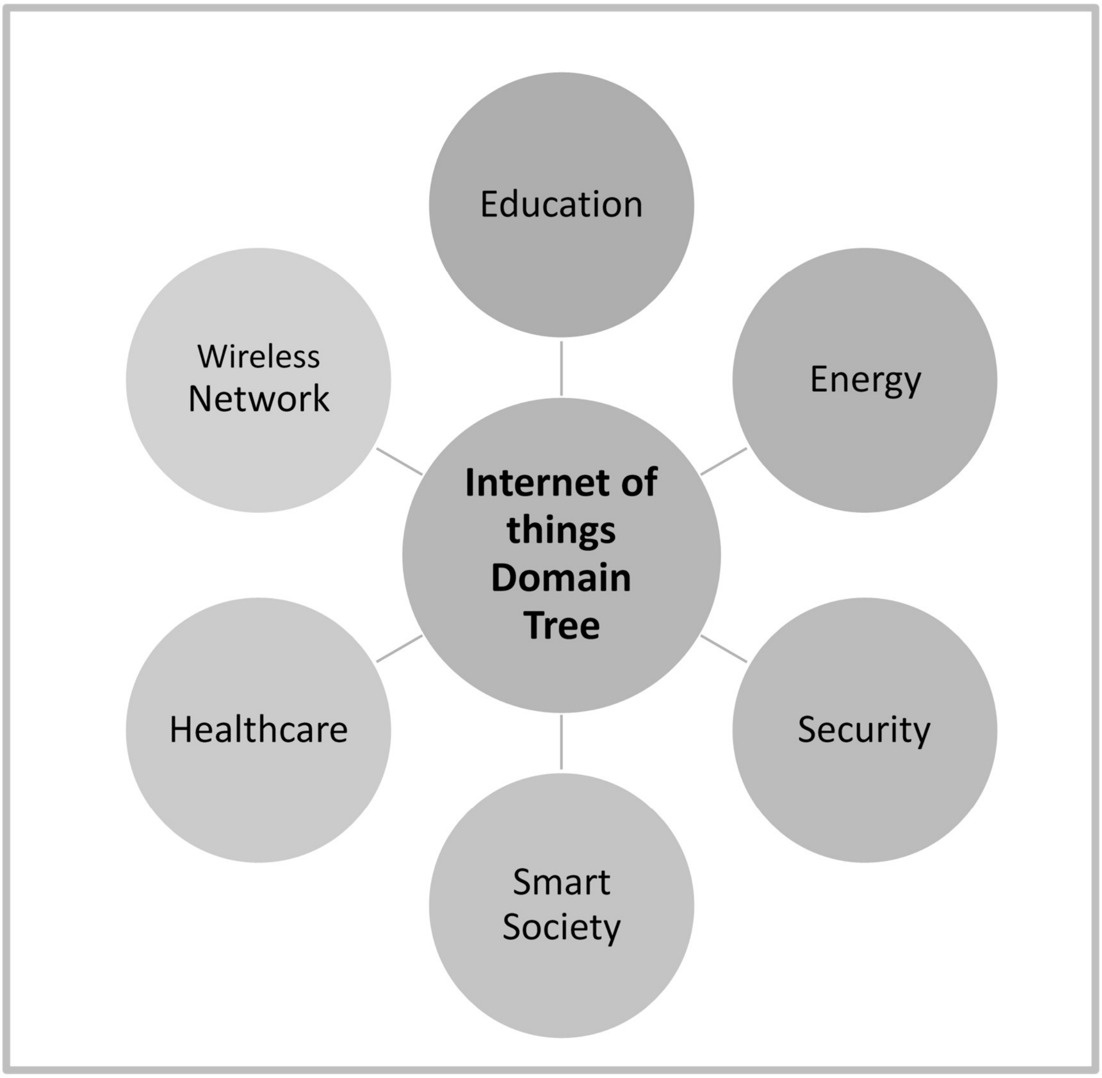


Figure 2.3: The internet of things domain tree (Ray, 2016)

- **Wireless technology:** The age of wireless internet technology is here, with more than 25 billion devices already connected in 2016 (Ray, 2016). However, only 3.9 billion people are connected to the internet (At the time of writing), which is roughly 45% of the population; therefore, much growth is expected as more users get access to the internet (Clement, 2018). The upgrade of 4G LTE to a 5G network will lead to new infrastructure being created, the overall size of the network increasing by 22 times the current size, and this new space will aid the growth of the internet of things. The rate at which the internet's speed is progressing leads to electronic devices becoming obsolete since they cannot fully utilise the internet. Therefore, new devices are created that can be used at these faster speeds; this cycle will most likely continue as we see the 5G networks grow into the future (Ray, 2016).

- **Energy:** The world is evolving and readily adapting technological advancements towards smart cities (Taneja, 2018). According to Taneja (2018), the path of least resistance to this goal is by significant unscaling utilities, the first significant utility that is already showing progress is energy. The unscaling of energy from primary non-renewable sources such as coal and nuclear power stations to unscaled sources such as solar power will undoubtedly have enormous impacts both economically and environmentally (Shahana et al., 2019). One major drawback with this system that needs to be accounted for is the additional electronic and electrical equipment required for set up and installation. The major components are the photovoltaic cell, the transformer and the storage unit; this type of electronic equipment have to be periodically replaced or refurbished, hence creating electronic waste.
- **Education:** The next major utility that will be unscaled is education, and this is already being demonstrated by online learning platforms such as Class Dojo, Khan Academy and YouTube Learn. According to De Souza et al. (2016), While these education services are revolutionary by nature, it does come with a drawback in bridging the education gap. This network does require many electronic and electrical components to function. The entire network is run on a cloud platform, which is a server farm that houses most processing equipment, then each user requires a laptop/PC and headset (De Souza et al., 2016). Analysis of the above scenario, we begin to grasp the volume of the electronic and electrical equipment in circulation and will be required in the future.
- **Healthcare:** In particular hospitals, the healthcare sector is a large consumer of electrical and electronic devices, from the use of desktop computers for admin purposes to advanced medical equipment (Ray, 2016). A case study conducted in brazil by Cairns (2015) concluded that an average hospital generated on average between 5 000 to 10 000 Kg of e-waste per year. When considering the number of hospitals in any given country, the volume of e-waste is significant. Over the past two

decades, the personal/home healthcare industry has grown in both ranges of types and complexity (The National Academies Press, 2020). The industry has been commercialized, cheaper and more affordable products available to the masses, and ranges from fitness items, such as fitness trackers and heartbeat monitors, to more intensive care equipment such as ventilators and nebulizers (Thakur & Anbanandam, 2016). The consumer health care industry is relatively young, and much growth is expected in the future, and as a result, a large volume of electronic waste is expected (Thakur & Anbanandam, 2016).

- **Security:** According to Goldfine (2018), the security sector has seen rapid growth in recent years in response to the evolving nature of worldwide threats, including cybercrimes, active shooter scenarios and terrorism. Therefore, adopting ever-adapting surveillance and security monitoring systems has been implemented in developing smart cities to aid in mobile crowdsourcing (Kong et al., 2019). An example of a smart city in development in Singapore, as it began the installation of smart cameras and developed its cloud platform to analyse the data generated (Richthofen et al., 2019). The cloud platform then can be used to analyse a multitude of events such as monitoring waste management services (littering), establishing where available parking's are around the city, measuring crowd density and the movement patterns of people (Kitchin, 2018). The new cloud platform software is being developed to analyses how crowds react to explosions, how an infectious disease spreads and how to optimise waste management services (Zaheer, 2019). The development of smart cities is already in progress in some parts of the world, and the rest of the world will shortly follow; therefore, we will see the employment of more surveillance equipment and data centres; this trend will lead to an increase in e-waste (Curzon et al., 2019).
- **Smart Society:** According to Naja et al. (2015), the rapid development of technology has seen the development of cyber solutions for real-world problems and hence create a smart society. Some areas that have attracted the attention of cyber technologists are traffic and parking optimization, waste management and the smart environment (Naja et al., 2015). With the ever-growing number of road users, traffic and parking require solutions to ease congestion using optimization networks of road

signals being explored (Jin et al., 2017). The study by Regan et al. (2018) in Palo alto California, explored parking bay sensors' use to determine parking availability in a given city block (Regan et al., 2018). The study had great success and will be implemented at scale throughout the Palo a lot area later in 2020. In waste management, surveillance cameras in urban areas monitor garbage hotspots and report any abnormalities, such as when a pickup is not made or when littering occurs in public areas (Medvedev et al., 2015). The Smart environment is rapidly developing as a study by Gascó-Hernandez (2018) conducted in Barcelona set out to determine in motion sensors in streetlights would be cost-effective. The sensors would function at 20% luminosity and would only brighten when they detected a pedestrian. The study concluded that this technology's implementation would reduce the overall maintenance cost by as much as 65 % (Gascó-Hernandez, 2018). While the above mentioned will certainly help solve many problems, it will create a large electronic footprint that will turn into e-waste in the future.

2.6 Consumerism (Social drivers of future e-waste generation)

Consumerism is a social and economic order that encourages the purchase of goods and services in continually more significant amounts. In recent times, we have more items per person than we have ever had before, which will continue to increase in the future.

Moore's law describes that the amount of transistors in any given space will double every two years, and for the past 60 years, this has held true (Theis & Wong, 2017). This phenomenon has allowed electronic devices to continually become smaller while increasing processing ability to produce better electronic devices (Flamm, 2017). When comparing Moore's law with consumer purchasing patterns, we can draw a trend, approximately every 2.23 years, a person purchases a new mobile device. There is a clear relationship between the increase in product quality with consumer demand, which indicates that electronic devices' overall consumption will increase (Sands et al., 2016). The three primary influences of consumer electronics are obsolescence, economic factors, and relative social behaviour.

2.6.1 Obsolescence

There are two main distinctions to obsolescence the first is planned obsolescence, when products have come to the end of the natural life cycle and require replacement (Debnath et al., 2016). Planned obsolescence is usually applied to consumable goods such as batteries and cables designed to be regularly replaced. Perceived obsolescence is whereby electronic devices seem redundant compared to new electronic devices that pose improved characteristics such as processing speed and design (Kuppelwieser et al., 2019). The perceived obsolescence of older electronics is a significant driver in the consumer electronic market and has influenced the lifespan decline (Trauth, 2017). A factor that often influences consumer perceptions is product novelty; often, when a new electronic product is released, it has a novel characteristic such as a new operating system or wireless network connectivity (Laukkanen, 2016). Maeng et al. (2020) concluded that the next significant influence on the electronic industry 5G will lead to a complete overhaul of almost all electronic as they seek to be connected to this network (Maeng et al., 2020).

2.6.2 Economically

In keeping with Moore’s law, the size and nature of electronic devices and their various components are becoming smaller size. Therefore, fewer materials are required in the manufacturing of electronic devices (Ye & Kankanhalli, 2018). The decrease in size has made electronic devices more cost-effective; this is especially true for entry-level products. The consumer market's economic structure has moved away from direct purchase and more towards structured leases (Rosseau, 2020). Adopting structured leases, like monthly subscription-based services, has greatly influenced consumers as the relatively low monthly instalments have seen electronic devices become more accessible to the middle and lower classes (Mashhadi et al., 2019).

The combination of these two factors has dramatically influenced the number of electronic devices a person possessed, 2016 an average person owned roughly 3.64 devices (Smart Phones, Mp3 Players and laptops) which have sharply grown to 6.54 devices per person in 2020 (including tablets, smartwatches and gaming consoles) and this trend will likely continue, with more ordinary devices such as a watch now becoming smart devices (Chaffey, 2016; Statista, 2020).

2.6.3 Social Behaviour

The modern person is very social by nature, and communication is a central focus, however with the invention of smart devices, this communication is taken to the extreme as a study conducted by Deloitte (2016) concluded that over one-third of participants said that they use their smart devices over 50 times a day to check their social media (Deloitte, 2016). When the participants asked if access to social media a driving force was when they were to purchase a new electronic device, over 60% of them agreed, this concluded that social media influenced the amount of electronic devices purchased, this trend will likely continue as more users join the platform (Blackwell et al., 2017).

The trends noticed by Investopedia (2020) indicate that the bulk of annual electronic sales occurs during seasonal peaks. Approximately 30% of are annual sales are made during the Christmas season, and approximately 10-15% of annual sales during the weekend of Black Friday and Cyber-Monday (Investopedia, 2020). Humans are creatures of habits and often find themselves repeating patterns; this has led to many consumers buying electronic devices periodically instead of buying a new product to replace a broken or malfunctioning device. (Lahindah & Saihaan, 2018). An example is when a consumer's mobile phone contract expires, they renew the contract and get a new mobile even though their current mobile device is neither obsolete nor malfunctioning (Debra et al., 2016). This type of behaviour results in many consumers amassing a lot of electronic devices, even though they do not regularly use them.

2.6.4 Stock Piling

The gap between the total amount of electronic products sold and the volumes of e-waste generated, as shown in figure 2.4, is greatly influenced by consumers storing large quantities of this e-waste (Parajuly et al., 2019). A possible reason for this gap forming is that consumers do not dispose of all their electronics once they obtain replacements.

According to a study conducted in 2018 by Nowakowski in Poland, he concluded that most respondents store all of their IT technology and mobile devices, and the majority cited that the reason they did this was to keep it as a backup or use it for spare parts (Nowakowski, 2018). Most respondents indicated that they did not store large, small or lighting appliances, and most cited that they disposed of these items through municipal waste services (Glosér-Chahoud et al., 2019). The rate at which IT technology and mobile devices are being produced will most likely see this gap increasing in the near future. The toxic nature of most electronic devices makes it unsuitable for ideal long-term storage and can have adverse effects on both human health and the environment and should be immediately disposed of at the end of life (Pan et al., 2019).

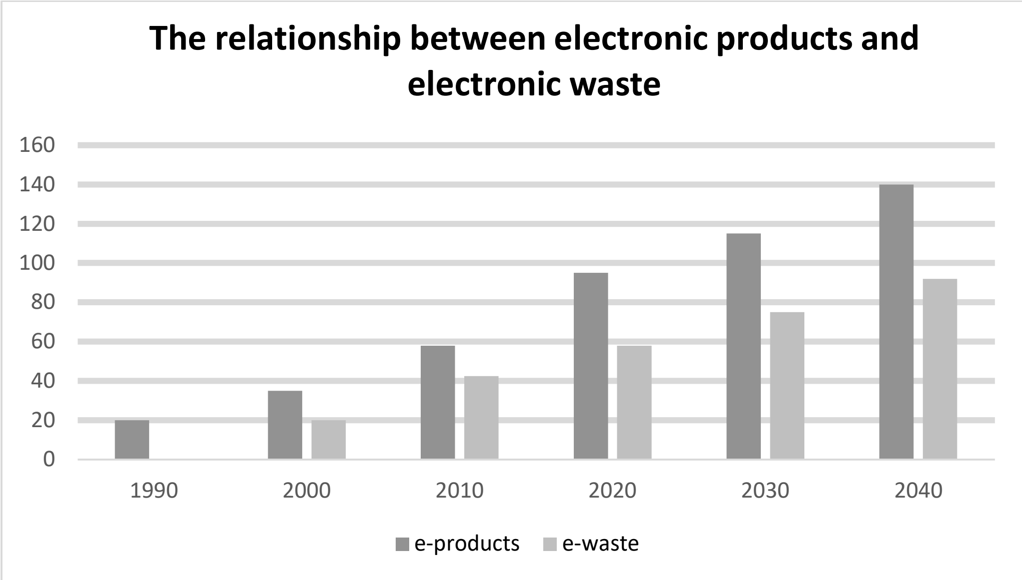


Figure 2.4: The relationship between electronic products and electronic waste (Parajuly, et al., 2019)

2.7 Sustainable development

The linear economy is drawing to a close, with the adaptation of sustainable practices significantly prompted. Therefore, many countries are moving towards sustainable waste management practices. In South Africa, there is a noticeable drive towards sustainable waste management practices with many educational programs centred around recycling and reusing of waste, an increase in recycling operations and legislation protecting against improper waste disposal.

According to Agamuthu et al. (2015), universities are considered the frontier for research and development often establish higher social responsibility standards and environmental conservancy than other institutions. This is one reason why the University of KwaZulu Natal (UKZN) is developing a waste management program called Green UKZN. The program's objective is to create an integrated waste management plan across all five of its campuses (Langa, 2019).

The purpose of the Green UKZN program is to create a waste management plan and ensure that the program is sustainable (Langa, 2019). According to Shriram (2018), the Green UKZN is influenced by many other well-established programs such as the Sustainable development goals (SDG's), The world in 2050 initiative goals and the objectives of the South African Research Chairs Initiative (SARCHI).

2.7.1 Sustainable development goals (SDG's)

According to the Global e-waste monitor (2017), the United Nations member states (which there are 193 over 50 are African) states adopted the 2030 agenda for sustainable development (Sustainable Development (UN), 2015). The agenda for sustainable development was adopted in 2015 and consisted of 17 sustainable development goals (SDG's) (as shown in appendix A, figure A9) targeted to end poverty, protect the planet, end poverty, ensure peace and prosperity. The rapid increase in the quantities of electronic waste combined with the improper and unsafe treatment and disposal through incineration or in landfills pose significant challenges to the environment and human health and the achievement of the sustainable development goals (as shown in table 2.5).

Table 2.5: Summary of sustainable development goals regarding electronic waste management (Sustainable Development(UN), 2015).

Sustainable development goals (SDG's)	Summary
8. Decent work Economic growth	The full and productive employment, aid in the growth of the middle class. The creation of sustainable economic growth and expand the economy. Governments and global initiatives can promote policies that encourage entrepreneurship and job creation. We can eradicate forced labour, slavery, and human trafficking. This goal in terms or recycling means that all recycling activities must be financially self-sustainable and do not require additional financial support to function.
9. Innovation	This goal aims to develop resilient infrastructure and promote inclusive and sustainable industrialization to foster innovation. The development of sustainable electronic waste recycling will require technological innovation and process development. These innovations can be applied to another area of waste management.

Table 2.5 continued

10. Reduce inequality	The gap between rich and poor is continuously increasing. The implementation of policies that allow for the creation of equally available jobs. Income inequality is a global problem that requires global solutions. That means improving the regulation of financial markets and institutions, sending development aid where it is most needed and helping people migrate safely so they can pursue opportunities. The successful implementation of a solid electronic waste management strategy will allow functional electronics to be given a second life through reusing and repurposing. These electronics can be made available to the poor in order to bridge the technological divide.
12.Responsible consumption	Ensure sustainable consumption and production patterns. The goal is to create a world where everybody gets what they need to survive and thrive. The consumption is conducted in a manner that preserves our natural resources for future generations. The circular economy's adoption can effectively accomplish this goal; the circular economy will relieve the pressure on natural resources and influence more sustainable production (Green Goods). The circular economy will also serve to create more responsible consumption patterns.
13. Climate action	This goal aims to take urgent action to combat climate change and its impacts. The current carbon emissions are at an all-time high, and the adverse effects are felt worldwide. Electronic devices' carbon footprint is relatively high as the manufacturing process emit high volumes of greenhouse gases; therefore, adopting a circular economy and recycling will significantly reduce the carbon emissions as the manufacturing process is by-passed.

The selected sustainable development's goal related to electronic waste management is shown in Table 2.5, the complete list of the goals is shown in appendix A9. These goals can be accomplished in pursuit of sustainable management of electronic waste.

2.7.2. The world in 2050 initiative

The world in 2050 initiative (TWI 2050) seeks to demonstrate how sustainable development goals can be achieved, ensuring prosperity, social inclusion, and good governance for all. The goal of the initiative was to create a plan to accomplish all the SDG's by the year 2050 across the world. The initiative brought together 150 participants from over 60 organisations that included policymakers, data analysts, modelling experts and analytical teams (TWI-2050, 2018). The initiative created a quantitative and qualitative framework comprised of six key domains, as shown in table 2.6.

Table 2.6: The six domains in the TWI 2050 (Sustainable development solutions network, 2019)

i.	Sustainable development is not only an environmental problem but essentially a societal problem. Human capacity can be advanced through improvements in education and healthcare, resulting in higher income and better environmental practices.
ii.	The circular economy's adoption will result in more responsible consumption and production, allowing us to do more with fewer resources.
iii.	The adoption of clean energy combined with energy efficiency, will make it possible to provide clean and avoidable energy for all. The achievement of the above will make it possible to decarbonise by 2050.
iv.	The development of more efficient and sustainable foods systems will allow equal access to nutritional food and clean water while protecting the biosphere and the oceans.
v.	Adopting smart cities as settlements will benefit the world population and the environment, with decent housing and connectivity.
vi.	The digital revolution, science, technology, and innovation will support the growth of sustainable development.

The six key domains give a people-centric perspective on building local, national and global societies with economies that enable the necessary wealth creation and the alleviation of poverty in any region of the world. The above domain may be used in the pursuit of accomplishing the SDG's but may not serve as their substitutes.

2.7.3. The South African Research Chairs Initiative (SARCHI)

The South African research chair initiative was established in 2006 by both the national research foundation (NRF) and the department of science and technology (DST). The initiative aims to improve research and innovation in public universities to produce high-quality postgraduate students and research outputs (SARCHI CHAIR, 2008). The key objectives that the SARCHI set out to achieve this are:

- Expand the scientific research and innovation capacity of South Africa.
- Improve South Africa's international research and innovation competitiveness while responding to its social and economic challenges.
- Create research career pathways for young and mid-career researchers with strong research, innovation, and human capital development output trajectory.

According to Trios (2020), the SARCHI Chair has created a set research criterion to evaluate the impact waste management has on the environment. The objective of the SARCHI is to produce research that is intended to aid the fulfilment of the SDG's in table 2.7 we can see how the research criteria intend to produce research to meet specific SDG's; these criteria are centred around waste management.

….

Table 2.7: SARCHI research criteria (SARCHI CHAIR, 2008).

Summary of criteria	Sustainable development goals (SDG's)
Where in the waste sector are we generating GHGs (and how much)?	Climate action (13)
What technology portfolio (lowest cost option) could achieve climate stabilization for your country waste sector and geographically where should they be located to ensure maximum impact?	Innovation (9)
What is the best scenario for your country waste sector to achieve a low carbon economy and what would be required for end-of-life technologies, waste collection systems (transportation), consumption, etc.?	Life on land (15)
In the Localisation of appropriate technology/infrastructure what are drivers/barriers (costs/tech feasibility) etc.?	Decent economic growth (8) Reduce inequality (10) Sustainable cities and communities (11)

2.8 The circular economy

The circular economy is an essential concept in sustainable development, and in the following section, we will discuss what a circular economy is and why it is important. The section will also cover how to create a circular economy and what are its natural limits.

2.8.1 What is the Circular Economy?

According to the Ellen MacArthur Foundation (2015), the definition of a circular economy is an economic system aimed at eliminating waste and the continual use of resources. In figure 2.5, the concept of a circular economy is illustrated. The traditional economy is linear; the product once consumed and no longer needed by the owner becomes waste (and ends up in a landfill).

The linear economy is no longer feasible, as the demand for raw materials is continuously increasing, and the age of the circular economy must begin (Gustavo, et al., 2017). According to Jawahir & Bradley (2016) in a circular economy, as shown in figure 2.5, resources are conserved and can be added back into the manufacturing cycle, thus relieving the environment's pressure from the harvesting of raw materials. The circular economy will reduce the number of raw materials harvested, which will decrease the overall amount of global warming potential emissions as most of the production cycle occurs in the harvesting, extraction, and refining of materials (Ellen Macarthur foundation, 2015). The circular economy naturally leads to better waste management practices as waste is treated as a resource, which will cause a decrease in pollution.

The circular economy can be created by implementing the waste hierarchy (as shown by figure 2.5) combined with introducing loops, slowing down flows and narrowing flows.

- ✓ **Creating loops** – when a product reaches the end of its designed operational life, it is reused, repaired or recycled rather than thrown away.
- ✓ **Slowing flows** – shifting to new ways of designing and making products ensures that they remain in use for as long as possible, thereby decreasing demand for new products.
- ✓ **Narrowing flows** – this involves shifting to more efficient ways of using products, e.g., sharing products or adopting product-as-a-service models.

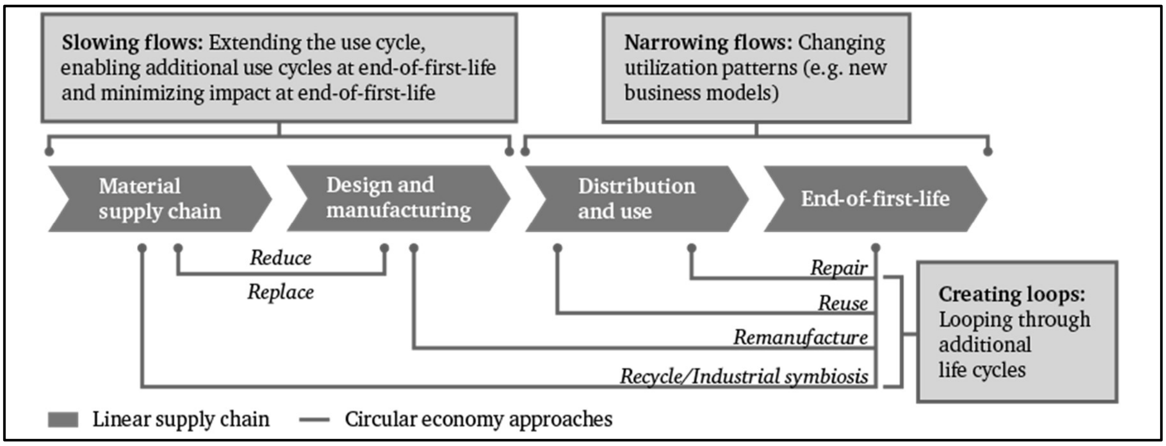


Figure 2.5: Circular economy activities (Jawahir & Bradley, 2016).

2.8.2 Drivers towards the circular economy

Many countries (including the African countries) seek to adopt a circular economy, mainly due to the wasteful and environmentally harmful nature of the linear economy. The age of the linear economy is maturing, and the following are the main incentive for adopting the circular economy (Hobson, 2016).

- Economic losses and structural waste:
  - ✓ The current linear economy is inefficient in utilizing the optimal value from resources. A study conducted by Preston et. al (2019), found that in Europe

material recycling and waste-based energy recovery captures only 5 percent of the original raw material value (Preston, et al., 2019).

- ✓ **For example,** in Europe, the average car is parked 92 percent of the time, 31 percent of food is wasted along the value chain, and the average office is used only 35–50 percent of the time, even during working hours (Govindan & Hasanagic, 2018).

- Price risk:
  - ✓ Companies and organisations have noticed that a linear system increases the risk exposure, mainly unstable prices and supply of resources (Williams et al., 2016).
  - ✓ The more prices fluctuate, the greater the uncertainty can become, creating a less stable economy. The last decade has seen higher price volatility for metals and agricultural output than in any single decade in the 20th century (Darby et al., 2020).
- Natural systems degradation:
  - ✓ A long-term problem to the economy is the set of negative environmental consequences related to the linear model (Jawahir & Bradley, 2016).
  - ✓ The depletion of natural resources and the degradation of natural capital are affecting the productivity of economies. Contributing factors to environmental degradation includes climate change, loss of biodiversity and natural capital, land degradation, and ocean pollution (Jawahir & Bradley, 2016).
- Advances in technology:
  - ✓ Information and industrial technologies are now coming online or being deployed at scale, which allows the creation of circular economy business approaches that were previously not possible (Tanweer , 2018).
  - ✓ These advances allow more efficient collaboration and knowledge sharing, better tracking of materials, improved forward and reverse logistics set-ups, and increased use of renewable energy (Tanweer , 2018).
- Regulatory trends:
  - ✓ In recent years, businesses have witnessed an increased effort on regulators to curtail and price negative externalities. Since 2009 (to present), the number

of climate change laws has increased by 66%, from 300 to 500. Carbon pricing, in the form of an emissions trading scheme or a carbon tax, has been implemented or is scheduled to commence in almost 40 countries and over 20 cities, states and regions (Mateo-Márquez et al., 2019). In Europe, 20 countries levy landfill taxes, raising revenues of €2.1 billion in 2009/2010. Against this backdrop, the call for a new economic model is getting louder (Lucas, 2018).

2.8.3 The circular economy in African countries

In recent times, many of the African countries are experiencing favourable demographics and fast economic growth which leads to new opportunities for growth and job creation through the expansion of industrialisation and urbanisation (PACE, 2019). The rapid growth raised much concern with African leaders, and the world economic forum (2016) launched a programme called the African Circular Economy Alliance. The programme was established by Nigeria, Rwanda and South Africa in the hope of accomplishing the following objectives (PACE, 2019):

- Share best practices for the creation of the legal and regulatory framework, the building of partnerships and the financing and creation of circular economy projects.
- Advocate for and raise awareness of the circular economy at a national, regional and global level.
- Bring about new projects and partnerships within an individual or multiple countries.

The African Circular Economy Alliance hopes that the above-mentioned objectives can help relieve some of the adverse effect of consumerism and establish a more sustainable society.

2.8.4 The limits of the circular economy

According to Korhonen (2018), the circular economy is still in its early stages from a scientific and research basis. At present, the circular economy (at scale) is a concept and therefore, many challenges need to be addressed (Korhonen et al., 2018). The main challenges identified by Korhonen (2018) are as follows:

- Thermo-limits (recycling efficiency):

    - ✓ The recycling of any product (including e-waste) cannot be 100 % efficient as energy and resources are required to create products and always produce residual waste at various processing stages.
    - ✓ The recycling process always consumes energy and may be less efficient than the use of virgin materials.
    - ✓ The circular economy (Reduce, reuse and recycle) are subject to thermos-physics and will ultimately lead to unsustainable resource depletion levels as the physical scale of the economy is not controlled.
- Economic growth:
    - ✓ The rapid progression of technology increases the efficiency of manufacturing, making new technology more economical at scale. The cost of repairs and refurbishment of electronics are not done at scale and can, in some instances, cost more than new products.
    - ✓ The slow adoption of second-hand goods will impact the progress of the circular economy.
    - ✓ Consumer behaviour is challenging to control, and the increase in the middle class and their available disposable income makes access to new electronics more accessible. This, in turn, hampers the acceptance of a circular economy and the adoption of green products.
- Degradation of materials:
    - ✓ The quality of some materials, i.e., paper, wood, and construction materials, decreases when recycled and cannot be reused for its original purpose.
    - ✓ The qualities of virgin material are different from those of recycled; many materials go through heating and chemical treatment and changes the structure. This means that the recycled materials cannot be used directly into the manufacturing process and may require treatment, and therefore uneconomical.

2.9 Integrated waste management

According to Memon (2017), Integrated solid waste management refer to the strategic approach to the sustainable management of solid wastes covering all sources and all aspects, from generation, segregation, transfer, sorting, treatment, recovery and disposal in an integrated manner, with emphasis on resource use efficiency.

The benefit of integrated solid waste management according to Memon (2017) is:

- ✓ Cleaner and safer environment.
- ✓ Higher resource use efficiency.
- ✓ Resource augmentations.
- ✓ Savings in waste management costs due to reduced levels of final waste for disposal.
- ✓ Better business opportunities and economic growth.

2.9.1 Integrated waste management plan

According to Gabriel et al. (2015), an integrated waste management plan is a system that covers all aspects of waste management from waste generation through collection, transfer, transportation, sorting, treatment and disposal. The data and information on waste characterization and quantification, and assessment of the current solid waste management system for operational stages provide the basis for developing a concrete and locally specific management plan (Taha, 2016). The foundation of a solid IWMP (shown in figure 2.6) is built on a thorough waste characterization and quantification (Including future trends). This is followed by evaluating the current waste management system and the exploration of gaps in management practices (Haan et al., 2017). The above steps are combined to set targets for the design of the integrated waste management plan.

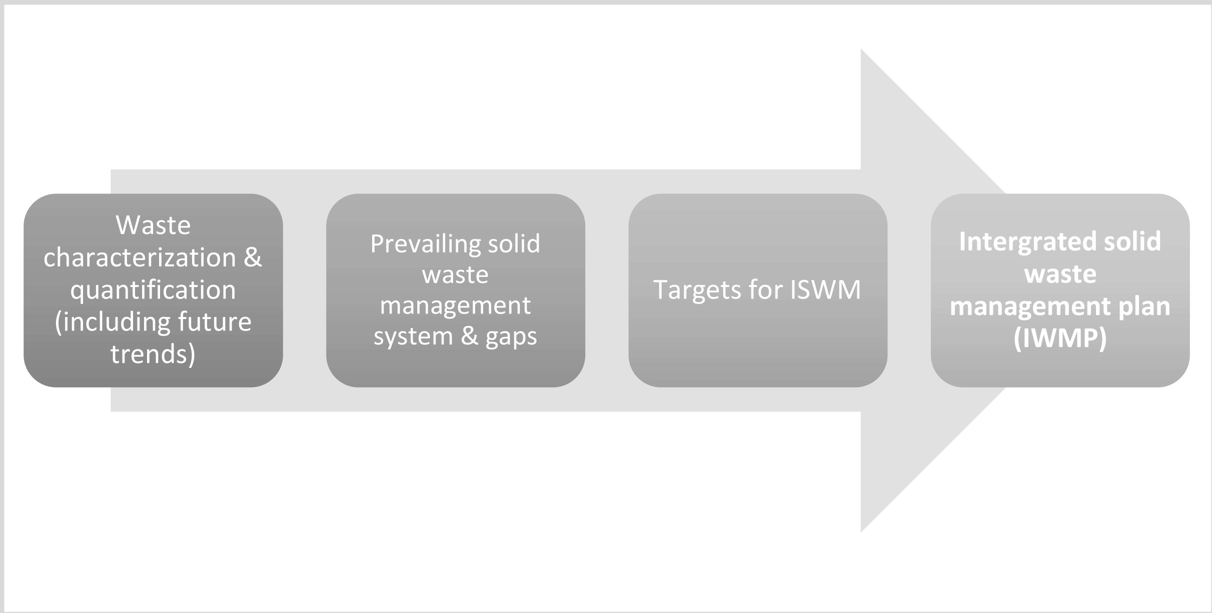


Figure 2.6: Integrated waste management plan (Haan, et al., 2017)

2.9.2 The decision support tool: W.R.O.S.E model

There are many decision-making tools are available to design an IWMP. According to Kissoon (2018), the most common options are the Waste Reduction Model (WARM), EASETECH, WRATE and the Waste Resource Optimization and Scenario Evaluation Model (WROSE).

The WARM model was developed by the US Environmental Protection Agency (EPA) to help solid waste managers to track and report GHG emission reductions. The model calculates GHG emissions for landfilling, landfilling with gas recovery (electricity generation and flaring), recycling, combustion, and composting. WARM uses GHG emission factors that were developed following a life-cycle assessment methodology.

The Easetech model was developed by the Technical University of Denmark. According to Clavruel (2013), Easetech focuses on material flow modelling using flow compositions as the basis for the LCA calculations. Easetech can be used to evaluate landfills, LFG recovery systems, recycling, anaerobic digestion, and aerobic composting.

The W.R.O.S.E model (Waste and resource optimization scenario evaluation model) is a zero-waste decision support tool (Trois & Kissoon, 2020). The model was developed to help South African municipalities and the private, and this model can be applied to most other developing countries.

W.R.O.S.E was developed by UKZN to evaluate GHG emissions for various waste management strategies including landfilling, LFG recovery, recycling, anaerobic digestion, and aerobic composting (Trois & Jagath, 2010). The model has since been revised and now incorporates landfill space savings and a basic economic evaluation analysis in the model. The WROSE model uses a Microsoft Excel spreadsheet interface to analyse the scenario.

This study will adopt the W.R.O.S. E model as its decision-making tool. The W.R.O.S.E model is a holistic method of analysis that includes sustainability indicators and has been used in many previous studies in South Africa (Trois & Kissoon, 2020). The W.R.O.S.E model can be used to develop and design an integrated waste management plan, based on a wide range of indicators. The current W.R.O.S.E model, which is primarily designed for organic waste, (as shown in Appendix A, Figure A3) is applied in practice defines each of the possible waste management scenarios (as shown in appendix B) and evaluates each scenario based on the criteria shown in tables 2.8 and 2.9 to produce the optimal solution (Trois & Kissoon, 2020).

Table 2.8: W.R.O.S.E model phase 1 indicators (Trois & Kissoon, 2020)

Phase 1 Indicators
1. Quantity of waste to be disposed
2. The composition of the waste stream
3. The cost of waste disposal
4. The potential greenhouse emissions
5. The potential revenue

The W.R.O.S.E model is currently under development to include economic, social, and institutional indicators. These indicators are referred to as Phase 2 of the W.R.O.S.E model and are shown in table 2.9. The inclusion of these criteria will create a more inclusive evaluation tool.

Table 2.9: W.R.O.S.E model phase 2 indicators (Trois & Kissoon, 2020)

Economic indicators	Institutional indicators	Social indicators
Collection quantities	Waste stream characteristics	Public participation
Job creation	Environmental legislations	Direct health risk
Health risk (at varies life stages)	Energy legislations	Indirect health risk
Public participation	Financial legislations	Public participation in waste management
Economic value of waste	Licences required	Public participation in EIA process

Dependent upon the various waste stream of the study, a variety of waste management strategies can be implemented (see chapter 3), these strategies can be used to create scenarios based on the desired end of life. The waste management scenarios are evaluated based on the above indicators, in the W.R.O.S.E model.

The scenarios are then evaluated by the above indicators, and the aims of the municipality, then the relevant final decision is selected. The W.R.O.S.E model (as shown in appendix A1) is highly effective in the decision-making process, as it quantifies indicators and allows multiple criteria to be evaluated simultaneously, creating a more inclusive solution (Trois et al., 2018). The W.R.O.S.E model, based on the criteria mentioned above, can be utilized to create and implement an integrated waste management plan as a climate change stabilization mechanism (Trois & Kissoon, 2020).

2.10 Life cycle assessment

According to Horne et al. (2019), the life cycle assessment is typically used to analyse the environmental burdens regarding a product, process, or service by investigating materials used and emissions generated at various stages of life. The assessment results can be used during the design stage of products to design environment-friendly products, and it can be used to minimise the amount of electronic waste generated (Horne et al., 2019). The essential aspects from the lifecycle assessment that will be discussed are the gas emissions from the various stages of the life cycle, the technology life cycle, and the energy consumption life cycle (Hauschild et al., 2018). The following life cycle assessments follow from the pre-production phases up until the usage phase; the end of life of the electronic product will be in the following sub-chapter.

2.10.1 Life cycle assessment: Gas Emissions

During the lifecycle of electronic devices, many dangerous elements are discharged. The gases that are of concern for this study are the global warming potential (CO & CO2), ozone depletion potential (Halogens, halocarbons), Human toxicity potential (cancer and non-cancer) and photo-oxidant potential, as these pose the greatest threat to the environment (Fiore et al., 2019).

According to li et al. (2019), most of the total gas emissions occur during the pre-production, where the raw materials are harvested and processed, and the production phase, where the electronic devices are made, as shown in figure 2.7. The gas emissions produced while the device is in operation (based on a 3-year life cycle) are relatively less than that produced during the production phase. Figure 2.7 shows the average of all the gases represented; the particular gas emissions are located in appendix A (Figure A4 - 8), with the most significant emissions being Global warming potential and ozone depletion potential, which is a significant concern for the environment (Li et al., 2019).

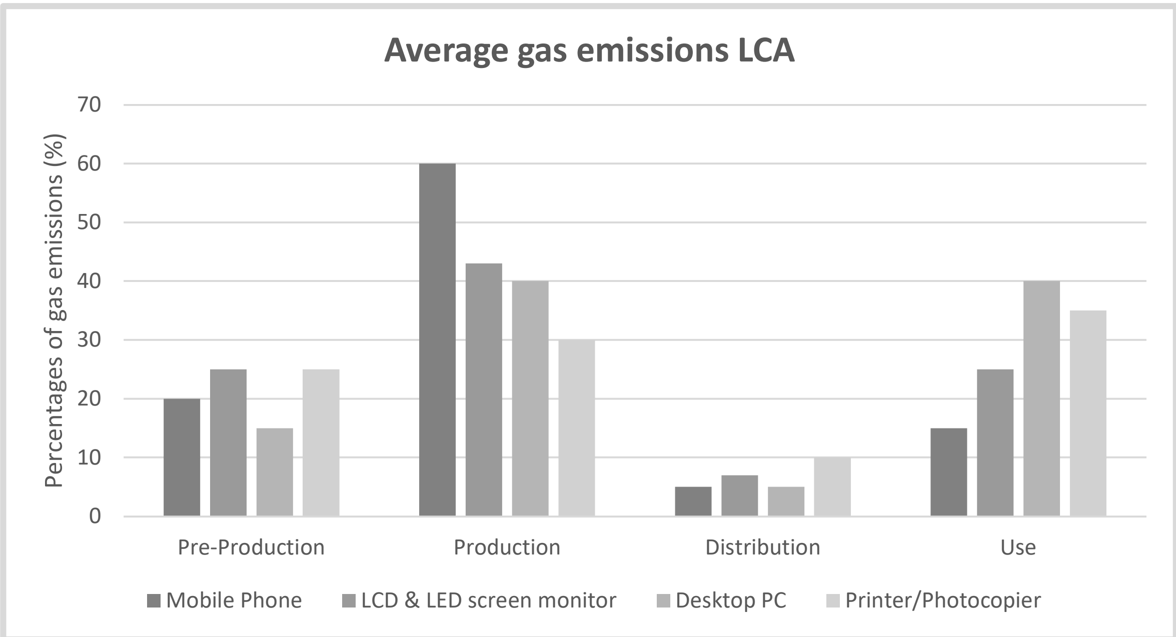


Figure 2.7: Average gas emissions LCA (Li, et al., 2019)

2.10.2 Life cycle assessment: Technology

Almost all technology goes through a normal life cycle, as shown in figure 2.8, with a period of growth where sales rapidly increase which leads to a decline in prices followed by maturity phase where competition is high and product usage is high final all technology goes through a decline and phase out (as shown in table 2.10) (Solomon , et al., 2014). The reason why it conformed normally is that it allowed for the products to have a reasonable life span and use materials and resources in a sustainable manner. This was the model that all electronic and electrical related technology conformed to, up until the internet revolution in the late 1990's (Byun, et al., 2017).

Table 2.10: Typical life cycle characteristics of a product (Solomon, et al., 2014)

Characteristic	Intro	Growth	Maturity	Decline	Phase-out	Obsolescence
Sales	Slow but Increasing	Increasing Rapidly	High	Decreasing	Lifetime buys may be offered	Sales only from aftermarket sources
Price	Highest	Declining	Low	Lowest	Low	Very high Aftermarket
Usage	Low	Increasing	High	Decreasing	Decreasing	Low
Part Modification	Cosmetic Only	Cosmetic Only	Cosmetic Only	Few	None	None
Competitors	Few	High	High	Declining	Declining	Few
Manufacturer Profit	Low	Increasing	High	Decreasing	Decreasing	Decreasing

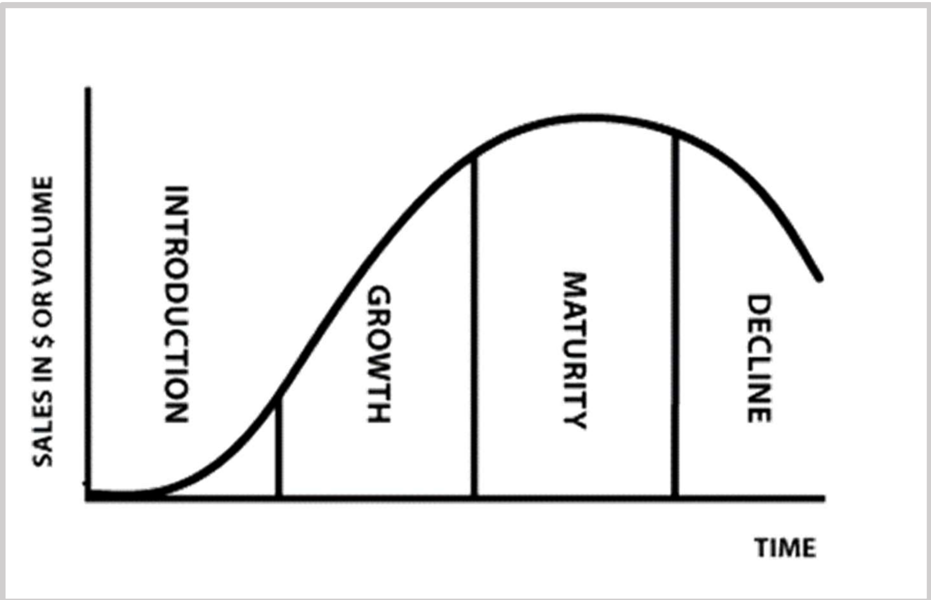


Figure 2.8: Normal product lifecycle (SmartSheet, 2020)

According to Park et al. (2015), the internet boom has disrupted the normal cycle and created what is known as a hype cycle, a hype cycle, as shown in figure 2.9. A hype cycle is when the normal technology cycle is interrupted by the second generation of technology while the first technology had not matured yet; an example of this is when the internet moved from landline to wireless in the early 2000s (Park et al., 2015). The main concern with the internet and the internet of things (IoT's) is that it rapidly evolves; as we see in figure 2.9, in the past 20 years, there have been five notable technological developments, and each one has led to a new growth phase in the industry (Solomon et al., 2016). The major downside is that the system does not have the chance to naturally cycle, and this leads to an increase in the production of electronic & electrical devices (overall electronics in the cycle increases), which when the next generation begins its growth phase, will become e-waste (Markard, 2018).

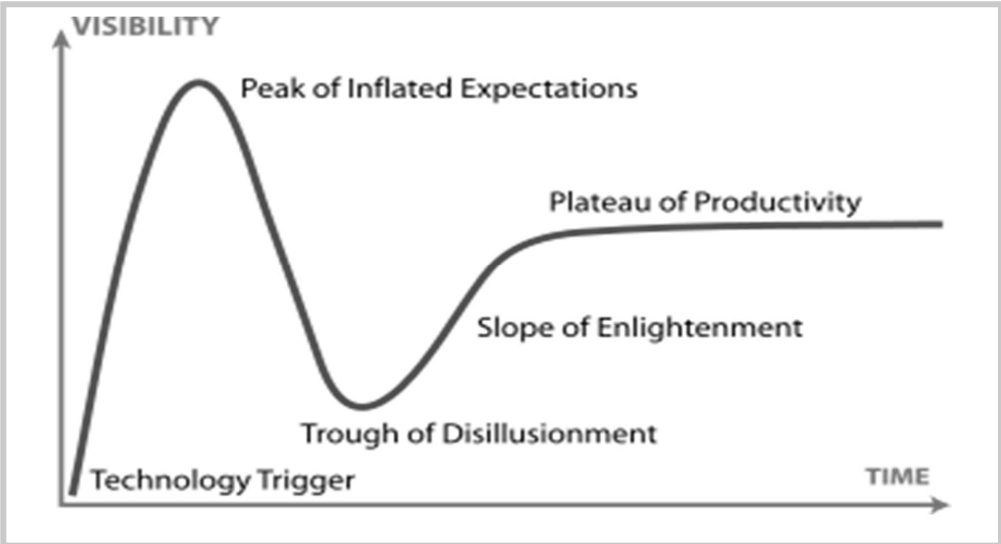


Figure 2.9: Hype cycle (Park, et al., 2015)

2.10.3 life cycle assessment: Energy consumption

According to Williams & Sasaki (2014), the energy consumed throughout the product lifecycle is shown in figure 2.10, in percentages as total energy consumption varies from each product. Most of the energy consumption occurs during the manufacturing phases and not when the actual devices are used (Othman et al., 2017). As shown in figure 2.9, the hype cycle is created by reducing the life cycle of electronic devices; this, in turn, increases the demand for new electronic devices. This increase in demand will lead to more energy being consumed in the production phases.

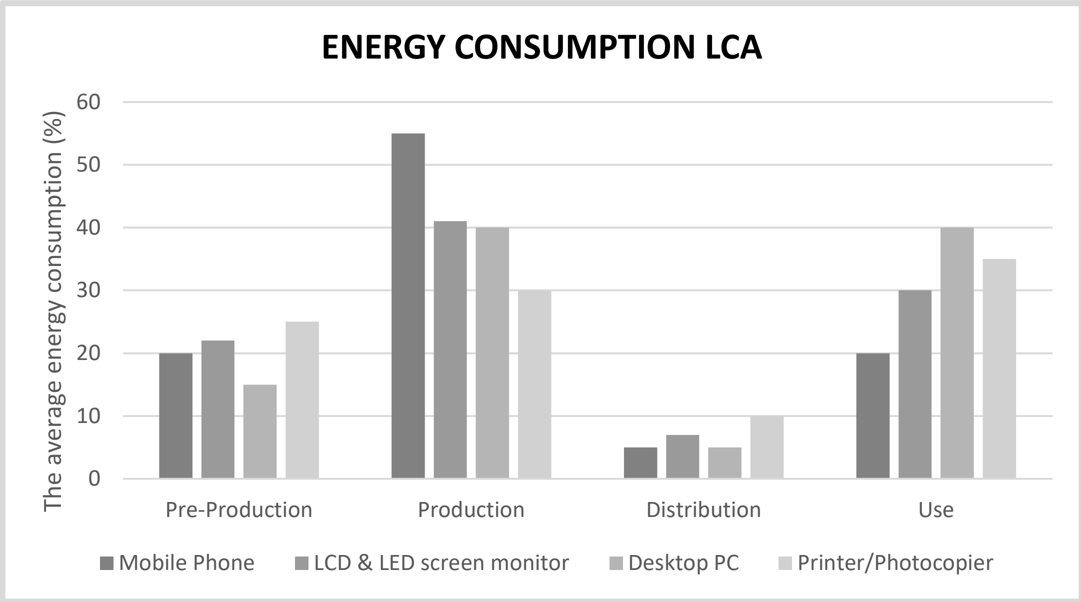


Figure 2.10: Energy consumption LCA (Williams & Sasaki, 2014)

The life cycle assessment that was conducted in the above studies illustrated that the majority of the harmful gas emissions and energy consumed occurred in the manufacturing phases. The end-of-life options will be discussed in the following sub-chapter.

2.11 Recycling of electronic waste

According to a study by Loomis and Ford (2013), concluded that e-waste is a highly recyclable waste stream, approximately 99% of it can be recycled. The general material composition of e-waste consists of plastics (usually from the housing and cable casing), metals (cables and electronic components) and silicon-based printed circuit boards (PCB) (Islam & Huda, 2020).

Therefore, an intense process (as shown in figure 2.11) is undertaken to sort and separate the various components; most of the e-waste can easily be physically separated and processed, such as the housing, cables, hard drives, and other metallic components; however, the printed circuit boards (PCB) required further treatment (Ruan & Zhenming, 2016).

According to Isildar et al. (2017), the PCB is complex as it has both metallic and non-metallic components and must undergo further treatment to extract the metallic fraction. The PCB contains many precious metals such as gold, silver and platinum; therefore, extraction of these metals can be lucrative.

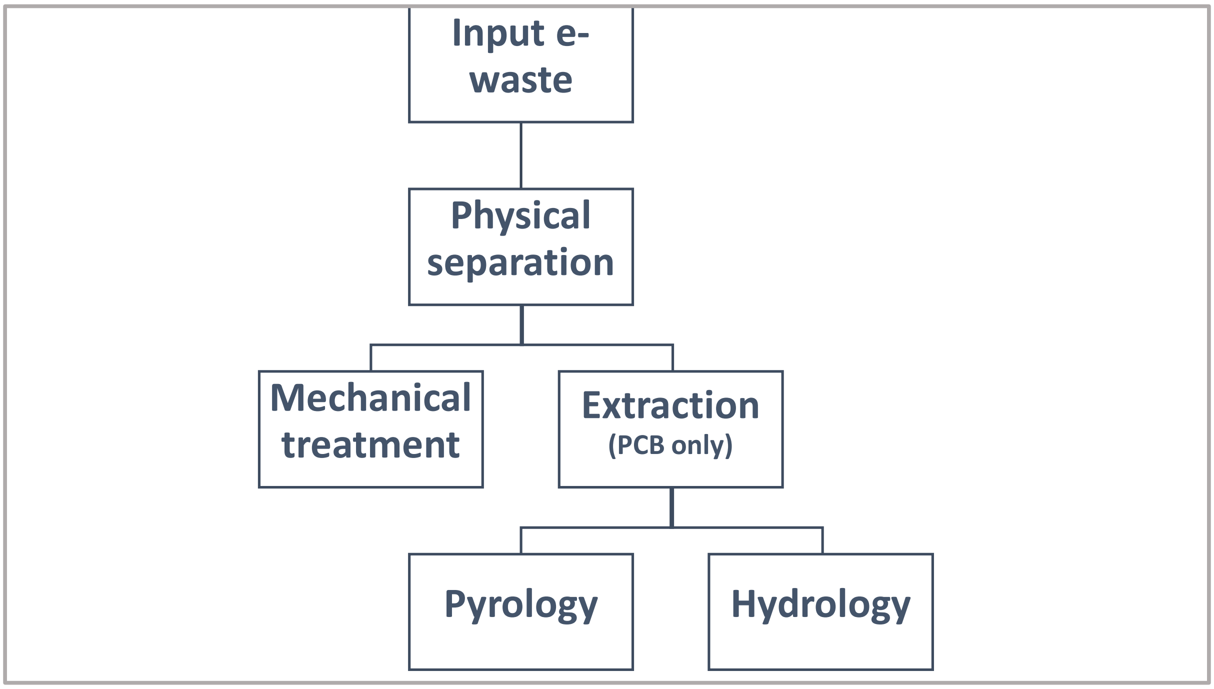


Figure 2.11: The recycling of e-waste

2.11.1 Pre-processing

According to Ruan & Zhenming (2016), e-waste must be processed before it can be treated. The processing involves the various components in e-waste to be first sorted and separated by hand, before being dismantled (Ruan & Zhenming, 2016). Most of the e-waste can easily be separated and processed by hand (Cesaro, et al., 2016).

There are three main groups of components in e-waste, the metallic fraction (support structures, outer casings, and fastenings.), the non-metallic fraction (Plastic housing, glass, and ceramics) and the printed circuit boards (PCB) (Ruan & Zhenming, 2016). In general, there are no emissions generated during the processing stage of the e-waste (Except in temperature exchange equipment, such as fridges there is a release of CFC gas, but this gas can be released in a safe manner), and overall pollution is low (Abdelbasir et al., 2018).

The e-waste is first pre-processed by mechanical means, the sorted and dismantled components are shredded (see figure 2.12), and then further magnetically separated into metallic and non-metallic fractions (Ruan et al., 2016). Most of the separated materials (aluminium, copper, and plastics) can be easily recycled; the e-waste is separated in terms of composition and distributed to the respective recycling agent. The copper is sent to a copper smelter, the aluminium is sent to an aluminium smelter, and plastic is sent to cold forming facilities that give it second-hand life as different items such as furniture (Gupta et al., 2014).

However, the printed circuit boards (PCBs) are complex and cannot be directly recycled. Therefore, the PCBs are separated and removed from the e-waste for further treatment (Kaya, 2017). According to Awasthi & Zeng (2019), the PCB in the most valuable component of electronic devices as most precious metals, such as gold, silver, and platinum, are stored.

The PCBs are complex and require a systematic deconstruction process (Awasthi et al., 2018). According to Cesaro et al. (2019), the first step is preparing the PCBs for the desired treatment process is size reduction. Most processes require the PCB to have a small and uniform size as this will speed up the treatment process (Awasthi & Zeng, 2019). The PCB is first shredded, then the portions containing ferrous metals and the portions containing precious metals are separated using magnetic separation (Cesaro et al., 2016). The final part of pre-treatment is the granulation to approximately 20 mm, and this size reduction will speed up the following treatment processes (Awasthi & Zeng, 2019; Cesaro et al., 2016).

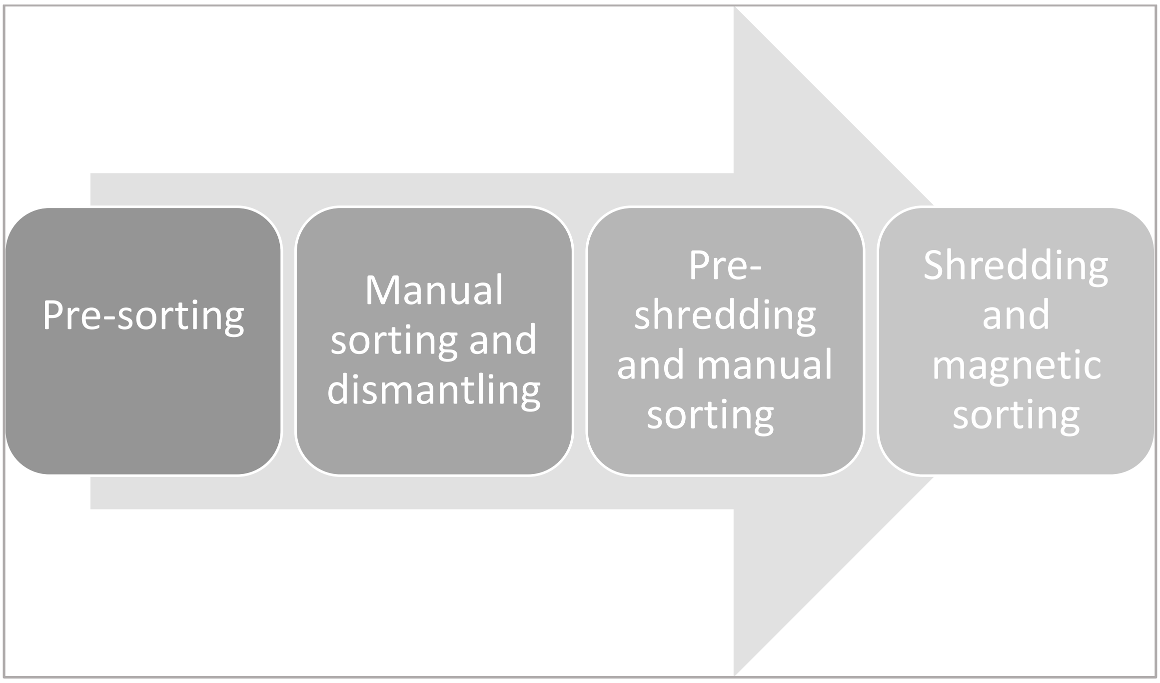


Figure 2.12: Pre-processing of e-waste (Cesaro, et al., 2016)

2.11.3 Pyrometallurgy of the PCBs

There are many methods of recycling printed circuit boards, but for the study, the focus is on the most common practices. According to Soler (2017), the most used methods of PCB recycling are pyrometallurgy and hydrometallurgy. The methods have been adopted in many countries and can be used at any scale.

The practice of using pyrometallurgy as a method of recycling WEEE is sharply declining, as concerns over greenhouse gas emissions (Shen et al., 2018). The gas emissions are shown in figure 2.13; there is high concentrations of carbon monoxide, carbon dioxide, and methane at different temperatures, which is the primary reason this method is sparingly used (Chiang & Lin, 2014).

The pyrometallurgy treatment method uses combustion to separate the different metals, as different metals melt at different temperatures. Non-ferrous metals such as aluminium and copper melt at lower temperatures than precious metals such as gold and platinum and, thus, are easily separated (Soler et al., 2017). The waste PCBs are placed into a thermal reactor, brought up to the relevant temperature to allow the metals to separate, then the materials are cooled and collected (Ortuno et al., 2014).

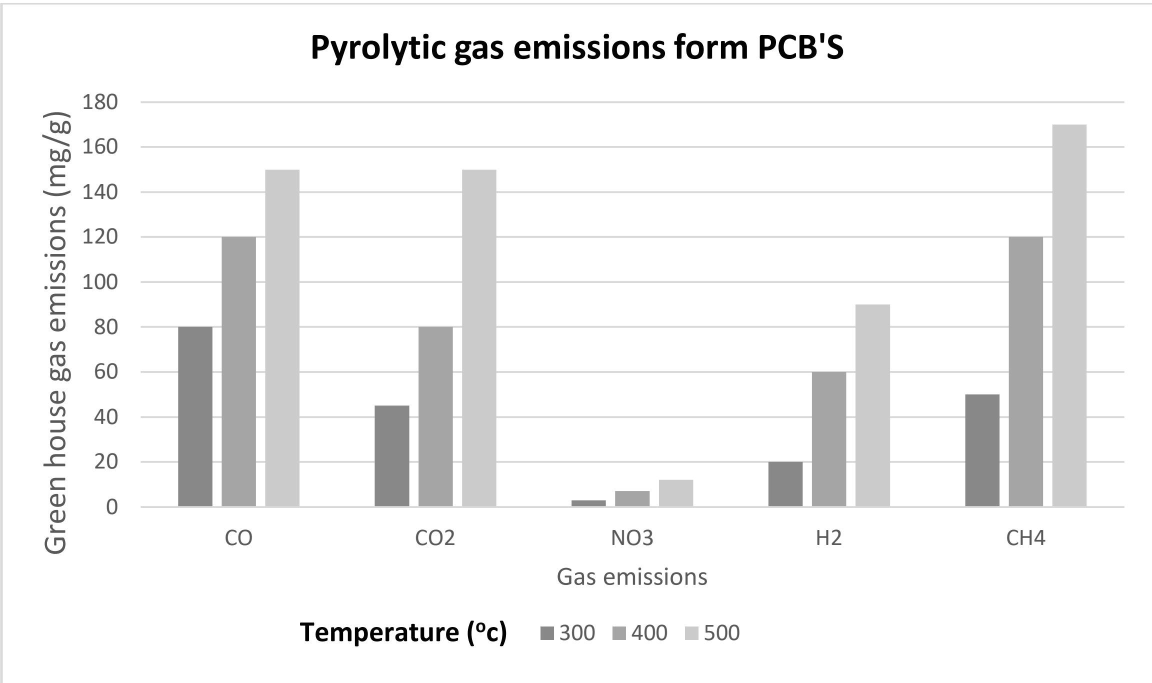


Figure 2.13: Pyrolytic gas emissions form PCB's (Chiang & Lin, 2014; Shen, et al., 2018)

The summary shown in Table 2.11 illustrates that using pyrometallurgy can be expensive (compared to alternatives) as it requires much energy to separate materials; the pyrometallurgy process is relatively quicker than other methods and can process large volumes. The recovery rate from pyrometallurgy is excellent, with a 92.5% efficiency across multiple metal categories (Soler et al., 2017; Ortuno et al., 2014).

2.11.3 Hydrometallurgy of the PCBs

According to Sethurajan, et al., 2016 there are three stages of hydrometallurgy, the first is pre-treatment followed by leaching and metal recovery. The PCBs must first undergo a pre-processing treatment as shown in figure 2.11. The PCBs are generally mechanically pre-treated by shredding and granulating into small fractions (<75 mm), the size reduction allows the downstream processes to be faster and more efficient (Pizzarro, et al., 2019).
Hydrometallurgy is the process that uses the leaching technique to separate the metals in a PCB from the silicon board; this process is a cost alternative to PCB recycling (Ashiq et al., 2019). After the pre-processing and pre-treatment, there are two main unit operations (as shown in figure 2.14) in the hydrometallurgy of e-waste. First is leaching (solubilization of metals from WEEE into leachates using aqueous chemicals) and metal recovery (selectively recovering the dissolved metals from the leachates) (Sethurajan, et al., 2016).

According to Cul & Anderson (2016), there are two different types of metal recovery. The first is the extraction of the base metals and the second is the extraction of precious metals. The first is the extraction of base metals such as copper and aluminium. The base metals are first leached from the PCBs by using acids such as sulphuric acid, hydrogen peroxide, or hydrogen chlorate, which react with the copper and aluminium, enabling them to form solids and separated from the leachate solution (Cul & Anderson, 2016). The metals are then extracted from the leachate using a strong base such as sodium hydroxide (NaOH) or hydrated lime ($Ca(OH)_2$) (Sethurajan, et al., 2016). These bases are commonly used as it is normally readily available and at a reasonable price compared to other bases.

The second is the extraction of precious metals, such as gold, silver, and platinum. The precious metal is leached using Nitric (HNO_3) or sulfuric (H_2SO_4) are commonly used, as it is generally readily available (depending on the country) (Tuncuk, et al., 2017). The metals are extracted from the leachate using a strong base such as hydrochloric acid (HCl) or sulfuric acid

(H_2SO_4) (Sethurajan, et al., 2016). The use of the above acids and base in general high recovery rates of approximately 99.5%. Alternative approaches to using the above acid leachate solutions of halogenated leaching (recovery rate 97.5%), thiourea leaching (recovery rate 82%) or thiosulfate leaching (recovery rate 98%) (Wu, 2017; Cul & Anderson, 2016).

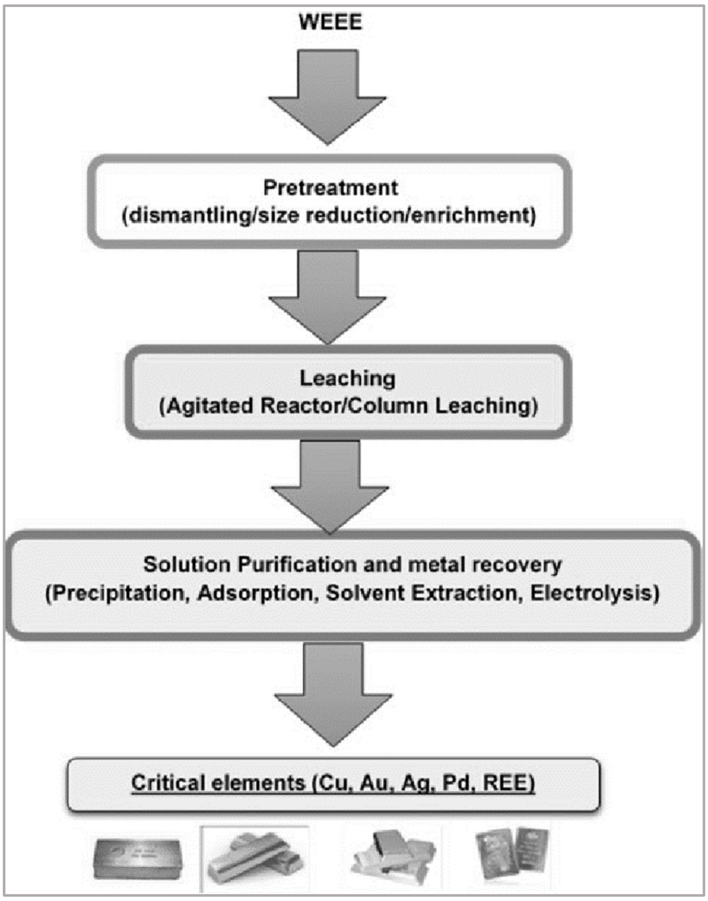


Figure 2.14: General flowchart of hydrometallurgy (Cul & Anderson, 2016)

According to Ashiq et al. (2019), the green side of using hydrolysis is that it emits a relatively low amount (compared to pyrolysis) of harmful greenhouse gases (ghg's), however while hydrometallurgy may not generate ghg's directly, it can consume a fair amount of energy through downstream processes (such as electrowinning/electro-refining.), hence contributing indirectly to ghg's emissions.

The various hydrometallurgy processes are relatively simple to set up and operate (Tuncuk, et al., 2017). Hydrometallurgy is more economical to set up and maintain compared to pyrometallurgy; however, the downside is that it can be a slow process, but it can be sped up by using a catalyst but not by much (Nikoloski & Ang, 2014). Hydrometallurgy can generate a significant amount of effluent which is required to be treated before disposal.

The comparison of the alternative for PCB recycling is shown in table 2.11, where pyrometallurgy has the shortest processing time but is expensive and has harmful environmental effects (Cul & Anderson, 2016). In a study by Shen et al. (2018), it was found that hydrometallurgy processes had a high recovery rate compared to pyrometallurgy however it had the longest process time. The use of either pyrometallurgy or hydrometallurgy require the use of pre-treatment, as mentioned above, and the processes such as shredding do require machines that consume electricity, hence also contributing to ghg's (Nikoloski & Ang, 2014).

While the result of the above study is not definitive, it serves as a guide for future research. The result from table 2.11 can be used when selecting which optimal extraction method is to be used for PCB recycling (Ortuno et al., 2014).

Table 2.11: Comparison of PCB recovery rates (Cul & Anderson, 2016; Shen, et al., 2018; Ortuno, et al., 2014)

		Pyrometallurgy	**Hydrometallurgy** (Based metals)	**Hydrometallurgy** (Precious metals)
I.	**Efficiency**	High (92.5%)	High (95.53%)	High (99.5 %)
II.	**Process time**	Relatively short	Long compared to Pyrometallurgy	Long compared to Pyrometallurgy
III.	**Economical cost**	Expensive compared to Pyrometallurgy	Moderately priced compared to Pyrometallurgy	Moderately priced compared to Pyrometallurgy
IV.	**Operation complexity**	Can be a complex technology to operate and maintain.	Simple technology	Simple technology
V.	**Environmental impact**	High emissions of ghg's.	Low emissions compared to Pyrometallurgy (however the full contribution to ghg's have not been account for I.e., energy consumption)	Low emissions compared to Pyrometallurgy (however the full contribution to ghg's have not been account for I.e., energy consumption)

2.11.4 Emissions from processing of metals

The metals recovered from the above recycling process are not immediately reusable and required heat treatment to be cast in a more usable form. According to Farjana et al. (2019), the most common metals recovered from the WEEE are copper and aluminium (most manufacturers are no longer using steel in electronic devices for environmental and economic reasons). The emissions from the recycling of metals found in standard electronic devices are shown in Appendix A (Figure A3-A7).

The heat treatment for recycled copper has two main stages: the smelting and the refining stage (Ghodrat et al., 2019). The heat treatment of process emits harmful gases, as shown in figure 2.15, the main emissions carbon dioxide, a global warming agent and CFC's, an ozone-depleting agent, both extremely harmful to the environment (Aarhaug & Ratvik, 2019).

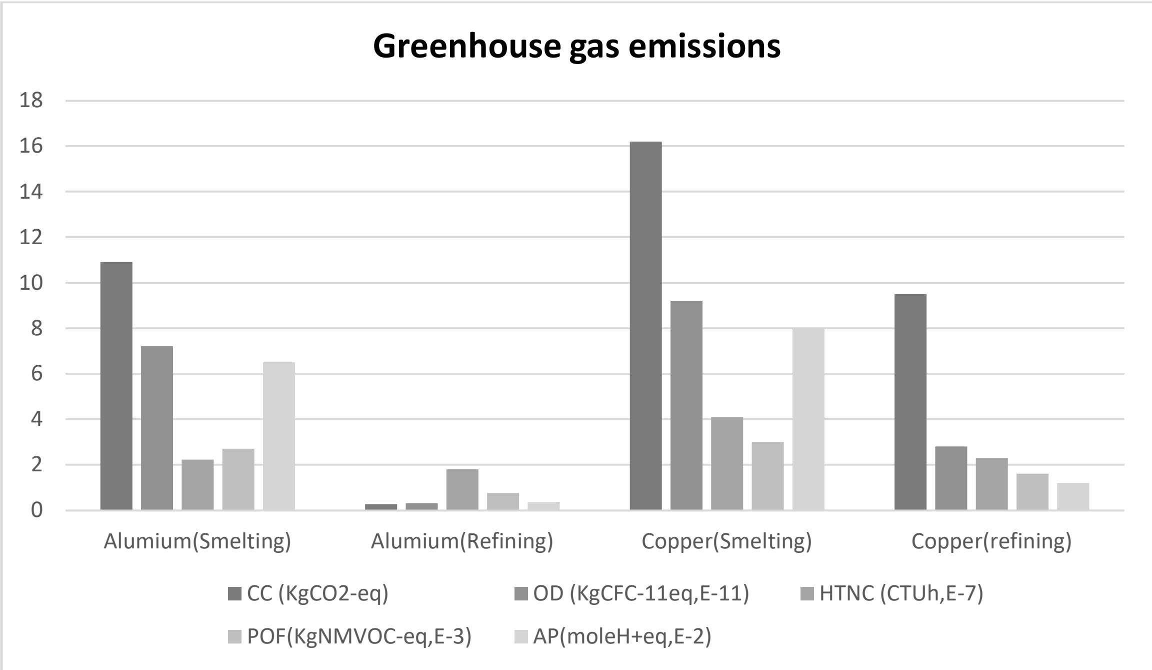


Figure 2.15: Emissions from heat treatment per tonne (Farjana, et al., 2019; Ghodrat, et al., 2019; Soler, et al., 2017)

The recycling of electronic waste cannot escape all harmful environmental effects, and hence a strategic analysis of all alternatives must be undertaken. From the above discussion results, it can be concluded that using pyrolysis will emit the most greenhouse gases, and therefore hydrolysis is favoured when recycling PCB's. The smelting of metals is unavoidable; however, smelting of recycled metals has less of an environmental impact, as the impacts from mining and extraction are eliminated; hence recycling has less of an environmental impact.

2.12 Toxic nature of electronic waste

If not responsibly managed, electronic waste can have adverse effects on both human health and the environment (Xavier et al., 2019). The material of concern is the heavy metals, as shown in Table 2.12, which once released from electronic waste becomes a problem. According to Singh et al. (2020), if responsibly managed, electronic waste is entirely safe, as it remains inert in its housing; however, when informal recycling methods are performed, the toxic material is realised. The following will illustrate which electronic waste materials are harmful and their effects on both human health and the environment.

2.12.1 Toxic constitutes of electronic waste.

According to Kumar et al. (2017), electronic waste is composed of many heavy metals and other toxic materials, mainly used to manufacture the printed circuit board and other components. The toxic material has adverse effects on human health and the environment (Kumar et al., 2017). In appendix A (Figure A1 & A2), the charts for Ecotoxicity, cancer potential and non-cancer potential are shown. The charts in Appendix A indicate that the highest concentration of heavy metals in electronics is cadmium (Cd), copper (Cu), Lead (Pb) and Mercury (Hg). The summary of where the most common toxic materials are stored in various electronic components are shown in table 2.12.

Table 2.12: Summary of the most common toxic elements of electronic waste (Kumar, et al., 2017; Wath & Katariya, 2017).

Substance	Applications
Cadmium (Cd)	Rechargeable Ni-Cd batteries Phosphor emitters in CRT screens Printer inks and toners, switches, connectors, semiconductor chips printed circuit boards plastic stabilizer.
Chromium VI (Cr)	Corrosion protection of untreated and galvanized, steel plates data tapes, floppy disks.
Copper (Cu)	Conductivity of printed circuit boards, cathode ray tubes, connectors electrical wiring.
Lead (Pb)	Solder in printed circuit boards Radiation shield in glass panels in cathode ray tubes (CRT) in computer monitors Batteries.
Mercury (Hg)	Cold cathode fluorescent Lamps Liquid crystal display (LCD) backlights Alkaline batteries, thermostats, sensors, monitors
Nickel (Ni)	Rechargeable Ni-Cd batteries electron gun in CRT screens Structural, magnetivity in steel housing, printed circuit boards, cathode ray tubes.
Zinc (Zn)	Anticorrosion coating cathode ray tubes
Rare earth elements	Fluorescent layer in CRT screens
Persistent organic pollutants	
Polybrominated diphenyl ethers (PBDEs)	Flame retardants for plastics
Polychlorinated biphenyls (PCBs)	Condensers, transformers
Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs)	Product of combustion
Polycyclic aromatic hydrocarbons (PAHs)	Product of combustion

2.12.2 The impacts on human health

According to Mehta (2019), the improper management of electronic waste can lead to toxic material exposure. The toxic material found in electronic waste has adverse effects on human health, as shown in table 2.13. The most common materials are copper which causes Anaemia, which leads to liver and kidney failure, Cadmium (which is grown in more recent products, as shown in appendix A), which is the most dangerous and can cause lung damage carcinogenic (Intrakamhaeng et al., 2019). Some of this toxic material is being phased out of electronics such as mercury and lead, while others increase in Cadmium and copper (as shown in appendix A, Table A6).

Table 2.13: Effects of toxic material on human health (Intrakamhaeng, et al., 2019; Mehta, 2019)

Substance	Health effects
Cadmium (Cd)	Kidney and lung damage; bone fragility; potential human carcinogen.
Chromium VI (Cr)	Liver and kidney damage; ulcers; convulsions; strong allergic reactions; asthmatic bronchitis; may cause DNA damage; a known human carcinogen.
Copper (Cu)	Anaemia; stomach and intestinal irritation; liver and kidney damage.
Lead (Pb)	Damage to central and peripheral nervous system, circulatory system; effects on brain development, interferes with learning abilities; effects on endocrine system and kidneys.
Mercury (Hg)	Chronic brain, kidney, lung damage; fetal damage; increased in blood pressure and heart rate; effects on brain function and memory; lack of coordination of muscle movements (ataxia) a possible human carcinogen.
Nickel (Ni)	Allergic reaction, asthma, chronic bronchitis, impaired lung function, potential human carcinogen.
Zinc (Zn)	Skin damage.
Rare earth elements	Cytotoxicity, cytogenetic effects; damage to lungs, liver, brain damage.
Persistent organic pollutants	
Polybrominated diphenyl ethers (PBDEs)	Endocrine disruptor neurodevelopmental dysfunctions.
Polychlorinated biphenyls (PCBs)	Liver damage, damage to nervous system, suppression of immune system, carcinogen.
Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs)	Impairment of the immune system Affects endocrine system and reproductive functions chloracne carcinogen.
Polycyclic aromatic hydrocarbons (PAHs)	Some are probable carcinogens.

According to Mehta (2019), toxic material in electronic devices is considered inert, and only when attempts to remove (or improperly stored) the material from the devices do they pose any harm. In a study, Nnorom and Osibanjo (2008) illustrated that when obsolete/redundant electronic equipment is disposed of in landfills or incinerated, it poses health risks due to the hazardous materials it contains. Table 2.14 summarises the methods of exposure and medium in which the toxic material inhabits.

The study conducted by Zielinski et al. (2018) in Agbogbloshie, Ghana, illustrated the elemental exposures of works in the electronic waste site. The workers were subjected to urinary testing, and results discovered that workers, especially participants who worked in dismantling and burning of PCB’s, had high levels of cobalt, copper, mercury and zinc. The researcher illustrated that since these elements are easily combustible, they can be quickly diffused into the air and inhaled (Zielinski et al., 2018). The participants were later interviewed, and results demonstrated that most participants were suffering from the adverse effects of e-waste, from mild cases such as headaches and skin damage to more severe cases such as reproductive, liver and kidney failure (Takyi et al., 2018).

A case study conducted by Awasthi 2018, in Guiyang, China, investigated the impacts of electronic waste dumpsites on local communities. The toxic materials in electronic waste seeped into the groundwater and entered a nearby river. A small village in Guiya used this river for drinking and bathing; the researcher interviewed a select group from this village. The interviews' results are that most of the people who used the river began to experience some concerns with their health. The participants were experiencing substantial digestives, neurological, respiratory and, in some cases, bone problems (Awasthi et al., 2018).

Table 2.14: Pathways to Environmental Contamination Due to E-waste Activities (Oi & Leung, 2019)

e-waste activity	Cause of contamination	Environmental media	Pathway
Open burning of e-waste (incineration)	Gaseous and particulate emissions	Air	Direct
	Combusted residue	Soil	Direct
	Wet deposition of gaseous and particulate emissions	Waster bodies	Indirect
Acid leaching of printed circuit boards (In landfills/dumpsites)	HNO_3 and HCL fumes	Air	Direct
	Dumping of acid leached printed circuit boards	Soil	Direct
	Dumping of acid solutions	Waster bodies	Direct
Heating of printed circuit boards	Gaseous and particulate emissions	Air	Direct
	Discarded pieces of electrical components	Dust	Direct
	Migration of contaminated dust	Soil	Indirect
	Migration of contaminated dust	Waster bodies	Indirect

2.12.3 The effects of electronic waste on the environment

According to Akortia (2017), there are significant quantities of heavy metals found in landfill sites that are believed to have originated from e-waste. E-waste if left undisturbed poses no significant problems, however, many landfill sites have frequent heavy compaction (via track-type dozer), this activity easily breaks e-waste and allows the heavy metals to be released (Gutberlet & Uddin, 2017).

According to Gutberlet & Uddin (2017), e-waste is often targeted by waste pickers for valuable metals and components. The waste pickers target garbage refuse bags (usually at the source of waste generation) and garbage at landfill sites (Gutberlet & Uddin, 2017). These waste pickers often are not technically trained to dismantle e-waste and often just break off the value materials, this improper processing of e-waste can release many of the toxic substances present (Gutberlet & Uddin, 2017).

The heavy metals, once released seep out of the e-waste into the groundwater, depending on the composition of the leachate, it can have various effects (Akortia et al., 2017). The leachate can enter a nearby water body or river and be exposed to the public, causing various health issues.

According to Montzka et al. (2018), the substances e-waste have a global warming potential (the gases found in temperature exchange equipment, such as CFS's), which can cause climate change and the depletion of the ozone layer, resulting from the limited capacity to adsorption emissions by the atmosphere.

Uchida et al (2019) has observed that electronic waste composed of older obsolete refrigerators, freezers and air conditioning units contain ozone-depleting chlorofluorocarbons (CFCs). This ozone-destroying gas escapes from electronic items dumped in landfills. According to Shuva et al. (2016), globally, e-waste results in approximately 5 000 tons of copper being released annually into the environment despite recycling efforts. E-waste does not only negatively affect the natural environment, but it also harms human health (Shuva et al., 2016).

A study conducted by Jibiri et al. (2014) concluded that many sites used as dumpsites for electronic waste could not be reused or repurposed as the heavy metals in electronic waste permanently affected the land's structural composition. The land cannot be used to grow vegetation and, in some cases, still have substantial quantities of heavy metals still present in sites long after the electronic waste has been removed (Jibiri et al., 2014).

2.13 Economic analysis

Electronic waste is a precious waste stream; however, only between 10-15% is recycled annually. Most of the electronic waste is mixed in with municipal waste and disposed of into landfills; however, in recent times, recycling has made significant progress, with many organisations becoming aware of the economic potential. Electronic waste recycling and landfilling have the potential to create many jobs.

2.13.1 Landfilling

According to Awasthi (2019), at present, over 80% of electronic waste in developed countries is not formally recycled and is either exported to developing countries or disposed of into landfills. The cost of landfilling is relatively high when consideration is given to the collection, transportation, maintenance, and labour (Danthurebandara et al., 2015). According to Omar & Rohani (2015) at present, landfills do not generate any revenue, except the harvesting of methane, which is still in development. Therefore, all landfills are financially reliant on municipalities for funding. When electronic waste is landfilled, the earth and precious metals cannot be recovered, therefore depleting the earth's reserves (Naidu et al., 2013).

According to Chandolias et al. (2015), heavy metals in electronic waste seep out and form toxic leachate, which has many harmful effects on the environment and human health (as shown in 2.12); a notable consequence is that heavy metals have a negative effect on methane production. Therefore, the toxic leachate must be treated in order for methane harvesting to become commercially viable (Chandolias et al., 2018). In 2016, South Africa generated over 350 000 tonnes of electronic waste, in which a significant portion was disposed of in landfills (SAEWA, 2017). Electronic waste takes up considerable landfill space, and when taken into consideration its impact on the environment, a case is made against its disposal in landfills.

2.13.2 Recycling

According to Heacock et al. (2016), electronic waste recycling is a sector in waste management that is rapidly growing; in 2010, only 5-7 % of all electronic waste was recycled; however, in 2016, approximately 10-15 % was recycled (Heacock et al., 2016). This industry's rapid growth primarily lies in the fact that electronic waste recycling is profitable, as shown in figure 2.16. Electronic waste recycling is self-sustaining and does not require government support to function; as shown in figure 2.16, the revenue obtained from material recovery and service fees is adequate to maintain future operations. (Khaiwal & Mor, 2019).

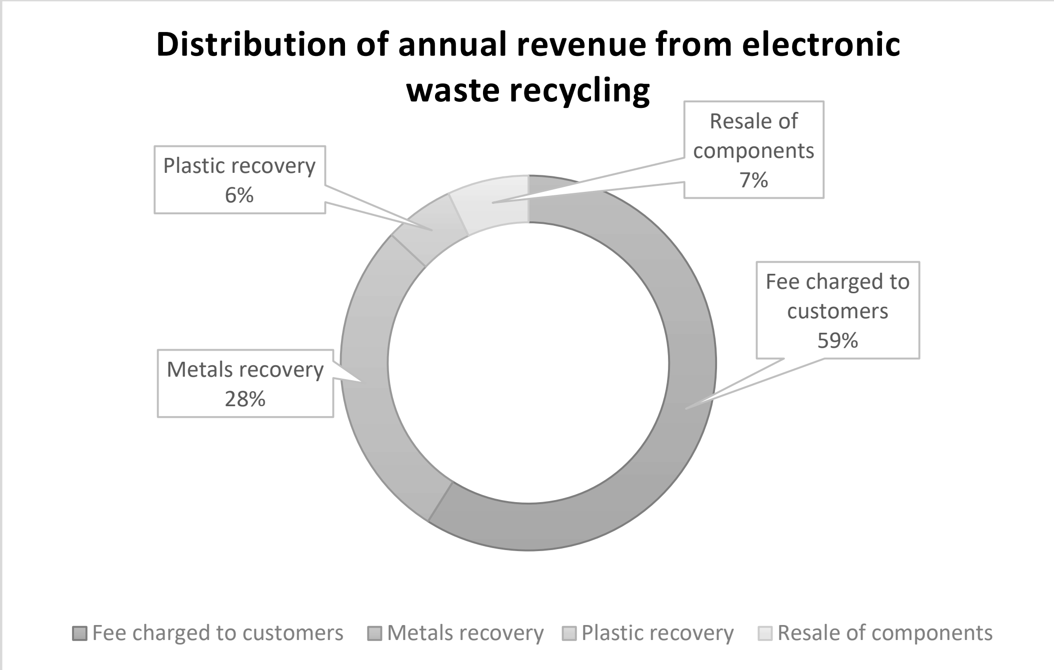


Figure 2.16: Distribution of annual revenue from electronic waste recycling (Khaiwal & Mor, 2019)

As illustrated above (in figure 2.16), the quantity of electronic waste generated is significant; electronic waste recycling will reduce the quantity disposed of in landfills to approximately 5-10%. Electronic waste recycling ensures that resources are conserved and can be added back into the manufacturing cycle. The operations shown in figure 2.17 illustrate the processes involved in electronic waste recycling why there will always be residual waste, and that recycling cannot be 100 % efficient.

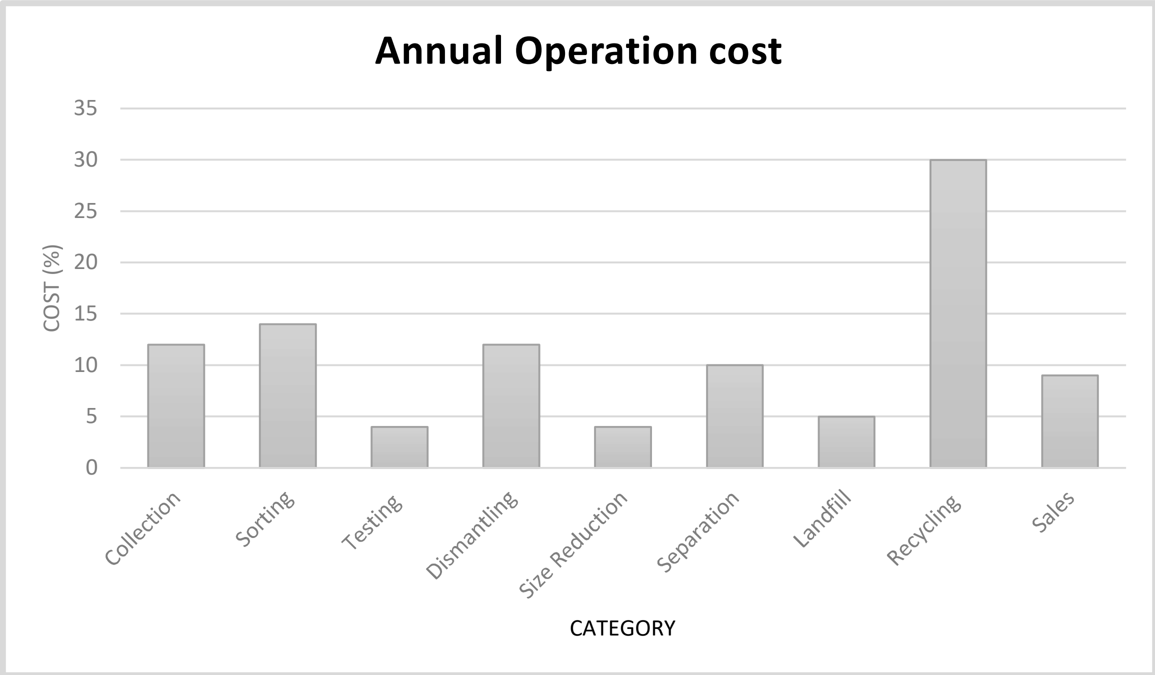


Figure 2.17: Annual Operation cost (Shakra & Awny, 2017)

2.13.3 The reuse and refurbishment of electronics

According to Khan et al. (2012), there is a severe lack of access to a computer and other electronic devices in developing countries. Therefore, many Africans do not have any computer literacy.

A study by level (2016) illustrated that the main reason for electronic disposal was perceived obsolescence (the old electronics were replaced by newer ones, even though the older electronics were still functioning). Therefore, many electronic are discarded that are still functioning. The reuse of older electronic devices can give many people access (especially those in developing countries) that cannot financially afford new electronics (LeBel, 2016).

According to Mellal (2020), a desktop computer only retains 30% of its original value after four years (after one year of use, it already losses 25% of its value). The sharp decrease arises from the electronic devices continual improvements, making smaller and faster devices, hence the increased demand (Mellal, 2020), however, this allows older electronics to be cheaper and accessible to more people.

2.13.4 Value of metals in electronic waste

Electrical and electronic devices contain up to 60 various elements (as shown in appendix A), many of which are highly valuable, namely the precious metals (such as gold, silver, and platinum) and earth metals (such as copper, nickel, and aluminium).

According to The United Nations University (2018), in 2016, there were 44.7 million tonnes of electronic waste generated, which is estimated to be worth 61 billion dollars. The economic value of these materials can make electronic waste recycling highly profitable. According to Awasthi et al. (2019), the manufacturing of electronic devices requires the materials mentioned above; however, there are finite quantities of material reserves and the future of the industry will depend on the circular flow of these materials.

The summary of the concentration of metals found in standard electrical and electronic products are shown in table 2.15 (the complete metal composition is shown in appendix A, Table A5). Most valuable metals are in the printed circuit boards (approximately over 80% of the precious metals are in Printed circuit boards). According to Streicher-Porte, et al. (2012), the components of a personal computer that have the highest economic value (due to gold plated connectors, components, pins, and transistors) are the:

- Motherboard (main circuit board)
- Peripheral Component Interconnect (PCI) boards (connects to the motherboard)
- Random Access Memory (RAM) (long, rectangular small circuit boards)
- Processor (a large chip that plugs directly into the motherboard)

Table 2.15: Value distributions of different materials in electronic devices (Lydall, et al., 2017).

Devices	**Value Share**					
	Base Metals Content			Precious Metal Content		
	Fe (%)	**Al (%)**	**Cu (%)**	**Ag (%)**	**Au (%)**	**Pd (%)**
Monitor Board	4	14	35	7	33	7
PC-board	0	1	13	5	69	12
Mobile Phone	0	0	6	11	71	11
Portable audio	3	1	73	4	16	3
DVD-player	15	3	30	5	42	5
Television	40	8	20	0.1	1	1

2.13.4 Job creation potential of e-waste recycling

According to Mostafa (2018), an average landfill will create one additional job for every 100 tonnes of electronic waste disposed of each year, while recycling electronic waste will create 36 jobs for every 100 tonnes of waste disposed of each year. Recycling will create more jobs than landfilling because of the longer logistic chain, as shown in table 2.16. Visvanathan & Modak (2013) stated that the jobs created by electronic waste recycling are well paying and can be declared as green jobs.

Table 2.16: Job creation potential of e-waste recycling (Mostafa, 2018)

	Landfilling (Potential Vacancy)	**Recycling (Potential Vacancy)**
Jobs per 100 tons	1	36
If all electronic waste is landfilled (10 000 tonnes, as an example)	100	-
If all electronic waste is recycled (10 000 tonnes, as an example)	-	3 600

2.13.5 Green jobs

According to Visvanathan & Modak (2013), there are many jobs created by e-waste recovery and recycling operations in developing countries. However, many of these recycling or waste management related jobs cannot be considered green as they do not match the basic requirements of decent work (Visvanathan & Modak, 2013).

According to Rutkowska-Podołowska et al. (2016), a green job should do the following:

- Eliminate child labour.
- Increase and improve occupational safety and health measures.
- Provide social protection and freedom of association (various forms of organizations of workers such as unions, local associations, and cooperatives).
- Provide decent and equal wage opportunities for women.

According to Ngomane (2015), the formal recycling and waste management sector in South Africa creates sustainable green jobs; however, the informal sectors do not fulfil the above requirements. The informal recycling sector is unregulated with no safety and health measures; children are often labourers, and wages are not fair or decent (Ngomane, 2015).

2.14 Legislations

According to Perkins et al. (2014), the adverse effects of electronic waste on human health and the environment in recent times has incentivised a global collective to support agreements to address the problems and challenges posed by hazardous waste. The purpose of the legislation is to regulate, authorise, outlaw or declare, from an environmental perspective.

This translates to serving and protecting the environment (Amuzu, 2018). At its core, legislations should serve as a guideline to achieve the best-recommended practice. Legislation are the fundamental building blocks in developing a sound plan (i.e., Integrated waste management plan) to combat the electronic waste problem. Therefore, priority must be placed on the development and enforcement of legislation (Machete, 2017). The electronic waste problem impacts each country differently, and therefore, a global representation is required to produce effective global legislations and guidelines.

This sub-chapter summarises the global, national, and local authorities who prioritise addressing the electronic waste problem and how they intend to achieve their respective goals.

2.14.1 Global legislations and guidelines

According to Perkins et al. (2014), the global leader in safe and sustainable electronic waste management is the Basel convention with 187 countries signed members, 30 of those being African countries (as shown in appendix A, Table A 12). The goal of the Basel Convention, as shown in Table 2.14, is to stop the transboundary movement of electronic waste from developed countries to developing countries. The Basel convention (2014) declared that the strategy to tackle this problem was to create a legislative framework to restrict electronic waste movement, as most of the report cases of the electronic waste problem from developing countries.

Another notable authority is the European union's WEEE directive (2012); this organisation aims to induce producer responsibility for the cost of collection and the recycling of their products, hoping that this will force the producer to manufacture eco-friendlier designs with extended end-of-life. This directive is legally enforceable by all member states of the European Union.

The STEP initiative (2014) is a global collaboration of micro-organisations; these are not necessarily the whole country but rather private companies, government organisations and academic institutes. The STEP initiative's objective is to facilitate the sustainable management of e-waste in an environmentally, economical, and socially sound manner. The STEP initiative's makeup is different from the previously mentioned and hence can address various aspects of the electronic waste problem that may not be covered.

The intended aim of the above mentioned is to protect human health and the environment against hazardous waste's adverse effects. Table 2.17 provides a summary of the organisations mentioned above, illustrating the similarities and differences and how each identifies and intends to solve the problem.

Table 2.17: Summary of international legislation

Name	The Basel convention	The European union's WEEE directive (2012/19/EU)	Solving the e-waste problem (STEP)
A. Governance type	United Nations Treaty, not legally binding serves as a guideline.	European union directive is passed as law in almost all member states.	Analyse and reports best practices, not legally binding serves as a guideline.
B. Goal	Aid in the mitigation of the transboundary movement of electronic waste from developed to developing countries.	Inducing Producer responsibility for the cost of collection and recycling of their products	To facilitate the sustainable management of e-waste in an environmentally, economical, and socially sound manner.
C. Structure	Global collective, with 187 member countries.	Collaborative management, from all European union members (European countries only)	Global collaborative of micro-organisations, members are companies, government organizations, international organisations and academic institutes around the world.
D. Proposed strategy	The creation of legislative framework to restrict the transboundary movement of e-waste and establishing a strictly controlled trading regime.	Imposing strong legislations on producers, extending responsibility into the end-of-life stages, in expectation that manufactures will initiate more eco-friendly designs and minimising waste.	Analyses the status of existing policy approaches on e-waste, and elaborates policy recommendations for future developments...
Reference	(Basel convention, 2011)	(European Parliament and of the Council european union, 2012)	(Solving the E-Waste Problem, 2009; Solving the E-Waste Problem, 2012)

2.14.2 National Legislations and guidelines

South Africa had no specific legislation regarding electronic waste until The National Environmental Management Waste Act No. 59 of 2008 was created. The Act is centred on the safe disposal of waste and makes it illegal for individuals or companies to dispose of anything that is considered hazardous waste; this includes electronic waste. Electronic waste (whether it's small mobile devices or large appliances) must be managed responsibly. Other legislations influencing the management of electronic waste are shown in table 2.18.

Table 2.18: Summary of the national acts and legislations

Legislation (or Act)	Summary
The National Environmental Management Act No. 107 of 1998 (NEMA)	The act focuses on environmental management and makes provision for waste management. The relevancy of this act to electronic waste management, is its focus on the avoidance or minimisation, and the remediation of pollution.
The Environment Conservation Act No. 73 of 1989 (ECA)	The act enforces the protection and the utilization of the environment. The part of the act specifically regarding waste management is located in act 20 and entails the minimum requirement for disposal of waste at a landfill site. The act stipulates the requirements, standards, and procedures for the disposal of wastes at landfills and other handling facilities (such as recycling plants).
The White Paper on Integrated Pollution and Waste Management (2000)	The paper regulates and establishes guidelines on the prevention of pollution, waste minimisation, impact management and remediation. The waste management hierarchy is illustrated in the white paper, • Minimization/reduction of waste. • Recycling and reuse. • Treatment and handling, and • Storage and final disposal.

The National Waste Management Strategy (NWMS 2008)	The purpose of the NWMS is to archive the objectives of the Waste Act No. 59 of 2008 and was created by a joint venture between the department of water affairs and forestry (DWAF) and the department of environmental affairs and tourism. The NWMS set targets for the reduction, re-use, recycling, and recovery of waste, and accomplishing this by developing integrated waste management plans for industry waste. The NWMS aids in the following: • integrated waste management planning. • waste information system. • general waste collection. • waste treatment and disposal. • capacity building, education, awareness, and communication, and • implementing instruments.

A list of Government Policies, National Acts, Regulations and Local Government By-Laws are shown in appendix A (Table A13) that regulate the control of hazardous substances in electronic waste. Whilst acceptable guidelines protect the environment and guidelines on how not to dispose of hazardous waste such as electronic waste; there are no enforceable legislation or guidelines for consumers.

2.14.3 Electronic waste associations/organisations in South Africa

According to Asante et al. (2019), in South Africa, while there are only a few, these electronic waste associations are relatively active. Each association's objective is to create awareness for specific electronic waste problems, hoping that a legislative will be created to support their goals (Asante et al., 2019). According to Ichikowitz & Hattingh (2020), the groups with the largest influence amongst all known organisations are the e-Waste Association of South Africa (also known as e-Wasa). The association had a strong influence in the Waste Act No.59 of 2008, as their primary objective was that the Act makes special provisions for electronic waste was successfully conducted (E-waste Africa, 2015). The summary of the organisation structure and proposed strategy are shown in table 2.19.

Another notable organisation is the South African WEEE producer’s forum; while it does not possess the same influence as e-Wasa, it still has importance to the electronic waste field (Ichikowitz & Hattingh, 2020). Manufacturers founded the organisation to ensure the formulation of sustainable WEEE industry waste management plans as detailed in the National Waste Management Strategy (WEEE forum, 2020).

A similar organisation to the above mentioned is the eWaste alliance, which is reserved for small businesses in the western cape. The importance of these above organisations is their independence to explore issues, the electronic waste problem is dynamic and ever-changing, and these smaller organisations can rapidly identify new developments (GreenCape, 2020). Shortly the rapid formation of organisations such as The e-waste alliance will occur, and their influence on the overall governance of electronic waste practices will be notable.

Table 2.19: Summary of South African affiliations

Name	e-Waste Association of South Africa (e-Wasa)	South African WEEE producer's forum	e-Waste alliance (Cape town)
A. Governance type	Collaborative governance with various stakeholders including manufacturers, suppliers, recyclers, and non-government organisations.	Industry self-regulation, with only some manufacturers present	Seeking something akin to a participatory guarantee system, made up of 5 businesses with a clear relationship to at least one manufacture
B. Goal	To establish an electronic waste management system that is sustainable and environmentally sound.	To ensure the formulation of sustainable WEEE industry waste management plans as detailed in the National Waste Management Strategy	To provide a ''one-stops hop'" for e-waste management, taking care of recycling, refurbishing, etc.
C. Structure	National association, one national body.	National association, one national body.	Collaboration of small businesses in the western cape.
D. Proposed strategy	Advanced recycling fee (ARF) also known as the green fee.	Multiple options including allowing manufacturers to contract recyclers to manage their e-waste	Collaborations of recyclers/ refurbishes principally in favour of an individual system approach

In conclusion, international legislation intends to address how one country's e-waste problem impacts others and enforces producers' responsibility at the end of life of electronic waste.

The national legislation (South African) intends to address the impact electronic waste has on human health and the environment within its borders and local associations aim to address the sustainable management of e-waste and contemporary issues that develop. Each of the above has a place, and each influence each other; therefore, all should be considered when developing any guidelines.

2.15. Previous studies

2.15.1 Past studies at The University of KwaZulu Natal

There have been many studies conducted at the University, the summaries and the key finding of selected studies are shown below.

Zero waste at The University of KwaZulu Natal (Howard College)

Malaza (2017) conducted a study on the Zero-Waste for post-consumer waste generated at the UKZN Howard's Centenary Building. A waste stream analysis showed that over a 3-week study period, 55.4kg of paper, 22.2kg of plastic and 10.3kg of metals were disposed of when they could be easily recycled (Malaza, 2017). The survey data showed that most of the buildings' users had no knowledge of Zero-Waste and did not partake in any recycling but were keen on learning and being involved in the initiative.

Sustainability Assessment at Howard College and Edgewood Campus

A 2015 study by Thajmoon investigated the similarities between waste management at UKZN Howard College and UKZN Edgewood Campus. The results obtained from DSW and the recycling contractors for Howard College show that 41% of the waste are recyclables, and 59% of the waste are non-recyclables. The proportions of recyclables are 42% white paper, 26% cardboard, 17% mixed paper, 5% plastic bottles, 4% cans, 3% glass bottles and 3% plastic (Thajmoon, 2015). The surveying aspect focusing on Howard college showed that around 80% of the group are educated and aware of general waste concepts, around 85% do not know about the waste cycle after disposal, and around 85% would be willing to contribute to improved waste management strategies.

Zero-Waste at The University of KwaZulu Natal (Howard College)

In 2015 a study by Ngomane researched the possibility of zero-waste at the Anglo Cluster Residences. A study found that 65% of the waste is biodegradable food waste, 39% of the waste are recyclables and 13% of the waste is non-recyclables (Ngomane, 2015). The recyclables consist of 16% paper, 10% plastic, 10% glass and 3% metal. A survey showed that the majority would like to participate in waste reduction and recycling campaigns.

2.15.2 Past studies involving e-waste is South Africa.

There have been a few studies that have dealt with e-waste in South Africa, the summary of selected studies is shown in table 2.20.

Table 2.20: Summary of previous studies that was centred around e-waste.

	Title and Author	Location and Year	Aim	Methodologies	Significant Outcomes
1	Exploring the potential for local end processing of e-waste in South Africa (Sadan, 2019).	Cape town (2019)	To discover what are the key challenges and barriers to implementing e-waste end processing technologies in SA.	• Analysis of literature and data. • Interviews with stakeholders.	• Optimization of new and existing technologies to manage e-waste. • Identification of factors influencing end processing technologies.
2	Towards the sustainable management of electronic waste: South Africa as a model (Okukpon, 2016).	Cape town (2015)	To determine what extent can the extended producer responsibility be applied in achieving sustainable e-waste management in South Africa.	• Analysis of literature and data. • Evaluating case studies.	• E-waste management through extended producer responsibility is highly effective. • Consumer participation greatly improves e-waste management.
3	The management of electronic waste: A case study of the Umbogintwini industrial complex and Southgate business park, in Kwa-Zulu Natal, South Africa (Govender, 2016).	Umbogintwini industrial complex and Southgate business park in Kwa-Zulu Natal (South Africa, 2016)	The aim of the study was to investigate the generation and methods of management of e-waste in the study area.	• Structured questionnaire. • Statistical analysis. • Tabulated results were used to draw conclusions	• due to the rapid technological advances, products are becoming obsolete much sooner; hence, the volume of e-waste generated globally is

					growing exponentially. • due to the hazardous nature of e-waste, it poses a serious environmental problem. • the Basel Convention banning the exportation of hazardous waste, this practice continues unabated;

2.16. Conclusion

From the above literature review, it is apparent that the volume of electronic waste generated both locally and globally is accelerating at a rapid rate, due primarily to the rapid pace of technological advances and the changes in the economy. Given the toxic nature of many components used in the manufacture of electronic equipment and machinery, e-waste can negatively impact both the environment and human health if not managed safely. The literature review concludes that there is no definitive e-waste management system in South Africa; however, many organisations have set up objectives and goals to archive sustainable waste management, and these can be used as a guideline. In the next chapter, the research methodology employed in the study is discussed.

Chapter 3: Research methodology and design

3.1 Introduction

This chapter intends to highlight the key aspect of how the research was conducted at the University of Kwa-Zulu Natal (UKZN). The objectives and how to obtain the desired result ethically are discussed. This is described by the methodology of how data is obtained and analysed. The chapter concludes by discussing how an integrated waste management plan for the e-waste management at UKZN was created using the W.R.O.S.E model.

3.2 Objectives of the research

The methodology presented in this chapter was designed to achieve the following objectives of the research:

- To evaluate the electronic waste stream at UKZN.
- To determine the current electronic waste management practices at UKZN.
- To design an integrated waste management plan (IWMP) using the W.R.O.S.E model appropriate for the sustainable management of e-waste in the university of KwaZulu-Natal.

The main recommendations derived from this study are directed primarily to UKZN management and decision-makers and potentially private organisations and other government organisations to demonstrate the long-term merit of the e-waste recycling industry and persuade them to invest in this sector.

3.3 The research design

The research design is intended to provide an appropriate framework for a study. The research design is based on the objectives of the research methodology. The following research design methodology, as shown in figure 3.1, was used in the study. The grey tabs refer to how data is to be collected and the green tabs refer to how the analysed data will be used.

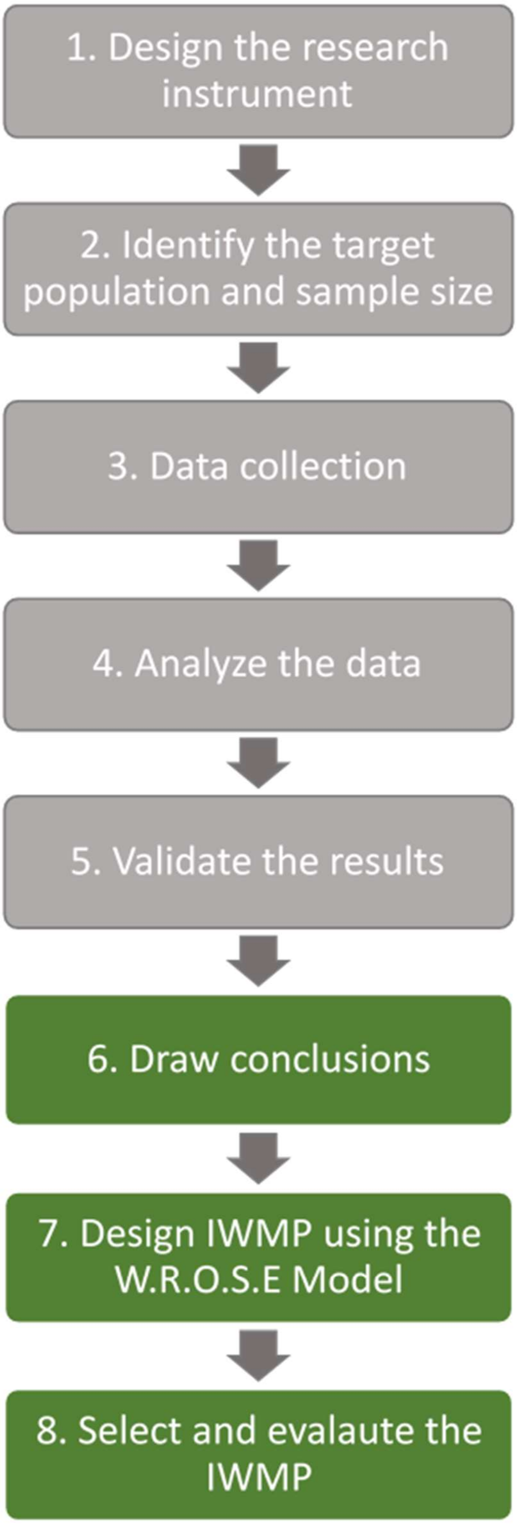


Figure 3.1: The research design

3.4. The Research instruments

The research instrument is crucial in obtaining relevant data, that is both reliable and valid. The research instrument selected for this study was a structured questionnaire. Structured questionnaires are efficient tools for systematically collecting data from a broad spectrum of respondents within a study area and are efficient in that many variables can be measured without substantially increasing the time or cost (Dörnyei and Taguchi, 2009).

The structured questionnaire was designed to link the questions administered and the data required (Poggenpoel and Myburgh, 2003). A sub-standard research questionnaire could produce poor results and will not meet the objectives of the study. A sub-standard structured questionnaire can lead to inconclusive conclusions, which voids the study's validity (Poggenpoel and Myburgh, 2003; Golafshani, 2003). In designing the questionnaire, the following constraints were adhered to:

- The questionnaire did not require confidential information from the respondents.
- The questionnaire was not complex and did not require background research to complete.
- The questionnaire was made by single response multiple-choice questions, to encourage participation.
- The questions were clear and comprehensible.
- The questionnaire was not lengthy and was designed to encourage participants to complete all questions.
- The questionnaire was structured, and the content was based on information obtained from the research objectives and literature review.
- The questionnaire was broken into sections, grouping questions of relevance together to achieve outlined objectives.

3.5 Target Population

The target population consisted of the campus staff that were responsible for the respective facilities within the UKZN. The University of KwaZulu Natal has many sources of e-waste, such as computer laboratories, lecture venues, offices (private and communal), libraries, in campus stores and building fixtures (lights, elevators, escalators and other fixtures).

Upon consultation with campus management staff (CMS), it was discovered that the highest concentration of e-waste originated from three key areas, the computer laboratories, the office areas (Communal) and the lecture venues. The study area consists of over 1000 (see chapter 3.6) different facilities that contain electronic devices. The above-mentioned types of facilities were analysed in the study, as shown in F 3.1.

Table 3.1: Description of sampled facilities

Facilities	Description
A. The Computer Laboratory	At UKZN some computers are available for all learners to perform academic activities, these facilities are known as computer laboratories. The computer laboratories are regarded as a high-density area, due to the high volume of electronics in a relatively small area, over 100 kg per room (Kang et al., 2005). According to Davis & Wolski (2009), the most common types of electronic devices used in computer laboratories are desktop computers, printers, projectors, LCD monitors and air-conditioning units.
B. Office Areas	There are two main types of offices areas at UKZN. The first is the Administration Office which consists of between three and five staff members. The second is the personal office areas which are reserved for lectures and other staff members. The office areas are regarded as moderately dense areas, as the volume of electronic devices to the area is modest, between 10-15 Kg per room (Liu et al., 2009). According to Davis & Wolski (2009), the most common types of electronic devices used in the office areas are desktop computers, printers, LCD monitors and air-conditioning units.
C. Lecture Venues	The quantity and composition of electronic waste streams found in lecture venues are consistent across all lecture venues. The lecture venues are regarded as low-density areas, as the volume of electronic devices per area is relativity low, between 4-5 kg per room (Kang et al., 2005; Liu et al., 2009). According to Davis & Wolski (2009) the most common types of electronic equipment used in the office areas are projectors, lighting equipment, audio equipment and air-conditioning units.

The computer LANS are most relevant to this study as they contain the highest concentration of electronic devices and contain the highest volume of electronic devices amongst all the facilities in the study areas. The electronic waste volume of UKZN is relatively high; therefore, it was selected to be the study area. Due to ethical reasons, permission was sought from UKZN representatives before the commencement of the study.

3.6 The Sample Size

The sample size was estimated using the sample size table developed by Sekaran and Bougie (2014). It was assumed based on the historical data of UKZN that a single campus has approximately 200 facilities (UKZN, 2018). Therefore, across all five campuses, there are approximately 1000 facilities.

It is assumed that one questionnaire will be administered in each facility to the responsible staff member; therefore, 1000 questionnaires are to be administered. For the purpose of this study administering 1000 questionnaires was not a feasible strategy, as it would be time consuming and laborious. Therefore, a reduced sample size, of which 95% confidence and 5% error was used.

Therefore, if the population is assumed to be 1000, using table 3.2 at the 95% confidence level and a 5% error, the appropriate sample size is 278. In table 3.3, the approximate number of questionnaires that are distributed at each campus is shown. The number of questionnaires that are distributed to each campus, as shown in table 3.3, was calculated using the sample size table by Sekaran and Bougie (2014).

Table 3.2: Sample size (Sekaran and Bougie, 2014)

Required Sample Size†								
	Confidence = 95%				Confidence = 99%			
Population Size	Margin of Error				Margin of Error			
	5.0%	3.5%	2.5%	1.0%	5.0%	3.5%	2.5%	1.0%
10	10	10	10	10	10	10	10	10
20	19	20	20	20	19	20	20	20
30	28	29	29	30	29	29	30	30
50	44	47	48	50	47	48	49	50
75	63	69	72	74	67	71	73	75
100	80	89	94	99	87	93	96	99
150	108	126	137	148	122	135	142	149
200	132	160	177	196	154	174	186	198
250	152	190	215	244	182	211	229	246
300	169	217	251	291	207	246	270	295
400	196	265	318	384	250	309	348	391
500	217	306	377	475	285	365	421	485
600	234	340	432	565	315	416	490	579
700	248	370	481	653	341	462	554	672
800	260	396	526	739	363	503	615	763
1,000	278	440	606	906	399	575	727	943

Table 3.3: Sample size at UKZN

	Computer laboratories	**Lecture venues**	**Offices**	**Total**
1. Howard	42	20	17	79
2. Westville	16	20	17	53
3. Medical school campus	3	20	15	38
4. PMB	23	20	17	58
5. Edgewood	11	20	17	48
Total	95	100	83	278

3.7 The data collection

The data collection process was undertaken by the use of the research questionnaire. Due to covid-19 restriction, all questionnaires were conducted electronically. The summary of the data collection process is described by the five W's of research, as shown in table 3.4 (Malhotra, 2010). The collected data is shown in appendix D.

The collected data were processed using Microsoft excel. Microsoft excel counted, stored, and manipulated data and was used to quantify attitudes, opinions, behaviours, and other defined variables (Landau and Everitt, 2003; Field, 2013).

Table 3.4: The five W's of research as applied to the specific case study.

Who?	The University of Kwa-Zulu Natal (UKZN).
When?	5th May to 22 May 2020
Where?	UKZN campuses (Howard, Westville, Edgewood, Nelson Mandela and PMB campus).
Why?	To investigate the potential electronic waste stream generated and the current management of electronic waste.
Way?	Use of a structured questionnaire.

3.8 Pilot Study

Nashwa et al. (2018) describe a pilot study's purpose to test the research questionnaire by inspecting the capacity to obtain desired data. The pilot test of the research questionnaire was undertaken to assist in detecting ambiguous questions, assessing the time taken to fill in the questionnaire, and determining if it was aligned to the study's objectives (Connelly, 2008).

The Centenary building at UKZN's Howard's campus was selected for the pilot study. This area was selected because it contains all three types of study areas. The Centenary building contains 3 computer laboratories, 10 offices and 8 lecture venues. There are a total of 21 samples available at the Centenary building, which according to Whitehead et. al (2015) means it is suitable for the pilot study.

According to Whitehead et. al (2015), a suitable pilot study should be between 15 and 30 samples or between 7-10% of the total population. The total samples across all 5 campuses are 278, hence 7% is 19 samples and 10% is 27 samples. The test was undertaken in the centenary building, and the results were analyzed (see, chapter 4). The required alterations and amendments were made to the research instrument.

3.9 Analysis of data

The research data analysis is a process used for reducing data to interpret and derive themes and patterns (Sgier, 2012). According to Sgier (2012), the data analysis process helps in reducing a large chunk of data into smaller fragments, which can be used to draw conclusions. There are three essential steps in data analyses namely data organization, summarization, and categorization (Sgier, 2012).

The data collected from the research questionnaire is to be analysed in order to quantify results and discover correlations. The analyses of data are crucial when drawing conclusions that are valid and reliable. There are two main types of data in this research, quantitative and qualitative (Miles, et al., 2017).

According to Sgier (2012), quantitative data is any data expressed in numbers of numerical figures are called quantitative data. Quantitative data is used to analyse the research and draw the conclusions of the study (Sgier, 2012). This type of data can be distinguished into categories, grouped, measured, calculated, or ranked. In this research, the quantitative data will be analysed in MS excel (Grbich, 2012). Quantitative data is used to compare the conclusion of the study with those of previous studies.

The quantitative data in this research was collected in section A of the research questionnaire. Section A will be analysed to estimate the potential volume of e-waste in the study area. The quantitative data will be tabulated, and the sum totals of the result will be used for further analyses. The qualitative data will be codified to tabulated results and conclude. According to Nardi (2018), statistics are used to summarise groups of data using a combination of:

- Tabulated description (frequency tables).
- Graphical description (line graphs, pie charts and bar charts).
- Statistical commentary (a discussion of the results).

According to Miles et al. (2017), qualitative data is when the data presented has words and descriptions, then it is known as qualitative data. Although you can observe this data, it is subjective and harder to analyse data in research, especially for comparison. Qualitative data is complex to analyse and it’s used to provide new insights and support the conclusions drawn from the quantitative data (Grbich, 2012).

The qualitative data will be collected in sections B and C of the research questionnaire. Section B and C will be analysed to determine the environmental, social, and institutional behaviour of UKZN towards e-waste. The benefit of using qualitative data in this research is that at UKZN a study of this nature has not been undertaken and the data may yield novel findings. The primary method of qualitative analysis in this research is finding patterns. The patterns of concern are the correlations amongst the different campuses, and what are the common themes.

3.10 Reliability and validity of the research questionnaire

The researcher's primary concern was that the data obtained, and the conclusions drawn were reliable and valid. The characteristics of reliable and valid research are the ability to undergo intense scrutiny, and if the research were to be repeated, the results would be the same (Roberts et al., 2006; Drost and perspectives, 2011).

"The reliability of the research questionnaire was checked by assessing inter-item consistency with the use of appropriate descriptive tests, including the calculation of the mean, medians and modes " (Govender, 2016). This ensured a high degree of reliability of the data collected through the questionnaire.

The definition of validity in terms of data research is the extent to which the method used to conduct research accurately measures the desired objectives (Kirk et al., 1986). To ensure valid and reliable data was obtained from the study, the researcher adhered to the following constraints (Kirk et al., 1986, Drost and perspectives, 2011):

- The prepared questionnaire is to be designed to address the research objectives of the study thoroughly.
- The data obtained and conclusions drawn should be checked against the literature reviewed to ensure the research questionnaire adequately covers the research.
- Conduct a pilot study to fine-tune research instruments, eliminate grey areas and potential errors.
- Attempt to achieve a large response from the study area.
- Do not engage in inaccurate or misleading measurement practices.

3.11 letter of information and consent

An introductory letter was attached to the questionnaire, disclosing the purpose of the research, and seeking consent to participate in the study (as shown in appendix B3). The letter allowed potential partakers to ask questions about the study, the researcher and the faculty receiving this research before deciding to participate in the research. The researcher also assured potential respondents that their identities and the identity of their organisations would remain confidential.

3.12 Maintaining ethics during research

The researcher's moral integrity, ethics, and findings are crucial in establishing the research credibility within its field (Orb et al., 2001; Ford et al., 2009). Ethical integrity is of the utmost importance when conducting any research but especially so when it is on behalf of an established organisation such as UKZN.

For this study, the researcher ensured that ethical integrity was maintained by (Ford et al., 2009):

- Attaching a letter of information and consent to all distributed questionnaires.
- Not engaging in deceptive methods to gather research.
- Ensured that the respondents were treated with respect and courtesy during the research process.
- The researcher assured the respondents that the information collected was confidential.
- For ethical use only, and that the respondents can withdraw at any time from the survey.

3.13 The waste stream analysis

According to Davis & Wolski (2009), the most common e-waste stream at higher education facilities is comprised of desktop pc's, printers/photocopiers, projectors, and air conditioning units (as shown in table 3.5). The above-mentioned waste stream is verified in a preliminary study (see chapter 4), as the largest quantities of e-waste were these electronic devices.

The research questionnaire will be used to calculate the quantity of e-waste generated. The weight of each electronic device was assumed by taking the average of the various models available. The researcher calculated the mass of each electronic device (i.e., All Desktops in the study area), then took the average, which is used in further calculations (see table 3.5). The average weight of the various electronic devices (shown in Table 3.10) when compared with the theoretical average weight (Chapter 2.3.1) differ slightly, for further calculations the data from table 3.5 will be used.

Table 3.5: Average weight of electronic devices (United Nations University, 2018).

Electronic device	Weight (Kg)
1. Desktop PC	14,5
2. Printers	34,5
3. Projectors	3,6
4. Air conditioning units	26

The volume of e-waste will be calculated by adopting the methodology that was used by Robinson (2009). Section A of the structured questionnaire will be analysed using the median of each range and multiplied by the average weight to determine the total e-waste generated, and the annual e-waste was calculated by dividing by the average lifespan of the electronic devices.

$$E = \frac{MN}{L}$$

Where E represents the contribution of an item to the annual E-waste volume (kg/year); M represents the mass of the item (in kg); N represents the number of units in service (and obsolete), and L represents the average lifespan (in years) of the item.

Figure 3.2: Annual e-waste formula (Robinson, 2009)

The Printed circuit boards (PCB's) will require further treatment to extract the metals, therefore the weight of the PCB's must be known. The average weight of PCB's is derived from past studies, as shown in table 3.6.

Table 3.6: Average weight of PCB's

Electronic device	Weight (g)	Reference
1. Desktop PC	1025	(Cucchiella, et al., 2015))
2. Printers	875	(Almutairi, et al., 2015)
3. Projectors	415	(Almutairi, et al., 2015)
4. Air conditioning units	325	(Lydall, et al., 2017)

3.14 Integrated waste management plan/Strategy (IWMP): W.R.O.S.E Model

The questionnaire will be analysed to determine the quantity and quality of the e-waste stream, and assess the social, economic, and environmental attitude towards e-waste at UKZN. The fore-mentioned results will be used to design an IWMP suitable for the University of KwaZulu-Natal.

The waste once collected by the UKZN waste management staff is transferred to a collection point whereby the waste is collected by a contractor. The contractor disposes of the waste to a landfill site. The information regarding the identity of the contractor was not available at the time of writing, however, the role and responsibility of the contractor were made clear by UKZN staff.

The contractor appointed by UKZN is to collect the waste from all UKZN campuses. The contractor dispatches separate collection vehicles to each campus to optimize the travel routes from collection to disposal (in the nearest landfill site, see table 3.16). Once the waste has been collected by the contractor assumes full responsibility for the waste disposal.

The IWMP must be able to quantify the environmental, economic, social impacts of zero waste management. The W.R.O.S.E^{TM} model will be used to analyse the multiple proposed scenario (solutions) evaluate the best alternative. The W.R.O.S.E^{TM} model will evaluate each scenario based on quantitative data (volume of e-waste, waste stream composition and lifespan) and qualitative data (environmental, social and institutional factors); therefore, the proposed solution will be holistic and comprehensive.

The W.R.O.S.E^{TM} Model which is a decision-making tool will be used fundamentally to create the IWMP for the University of Kwa-Zulu Natal (Trois and Jagath, 2010). The following are steps that will be taken to create the IWMP (Reddy, 2016):

- ✓ **Selection of e-waste strategies:** the selection of zero waste strategies suitable for e-waste management in South Africa.
- ✓ **Development of waste management scenarios:** incorporating these strategies to form an integrated waste management plan (IWMP) suitable and applicable for SA.
- ✓ **Multi criteria analysis framework:** definitions of the sustainability/feasibility criteria and environmental, economic, and social indicators.
- ✓ **Indicator Assessment Matrix:** selection of various indicators that will be used to evaluate the different waste management scenarios.
- ✓ **Validation/updating of selected indicators:** the methodologies of either updating existing indicators in WROSE or the validation of new indicators to be applied.
- ✓ **Development of WROSE Microsoft Excel interface:** into a completely integrated user-friendly interface.

3.15. The Research Questionnaire

The research questionnaire is designed to fulfil the criteria of the W.R.O.S.E model, the structured questionnaire is divided into three sections, the questionnaire consists of sixteen closed-ended questions multiple choice questions and one open-ended question which was intended to accommodate for additional comments (a sample of the questionnaire is shown in Appendix B1). The sections are the main criteria (Section A); economic indicators (Section B) and institutional indicators (Section C).

Section A, as shown in table 3.7 will cover the W.R.O.S.E model's main indicators, Questions 1-5 will determine the quantity and quality of waste. Hence section A will be used to determine the waste stream of each campus. The structured questionnaire will only include the most common sources of e-waste, and with the aid of the literature review and table 3.1, it was determined that the most common e-waste sources were desktop computers, printers, projectors, and air conditioning units. Question 6 will determine the life span of e-waste and hence determine the maintenance cost, the average cost per month.

Table 3.7: Economic indicators tested in the questionnaire.

Economic indicators	Related section in the research instrument
Quantity of e-waste	Section A: Question 1-5
Quality of e-waste	Section A: Question 1-5
Maintenance cost of disposal	Section A: Question 6 Section B: Question 8, 9 & 10
Economic value of waste	Section C: Question 16

Section B, as shown in table 3.8, will cover the W.R.O.S.E model's economic indicators; Question 7 explores how much information regarding electronic waste the participants are exposed to. Questions 8-11 seek to explore participants' management practice (as shown in table 3.8) if participants dispose of stored electronic waste and how they went about doing it. Question 12 aims to determine how significant an electronic waste management strategy is to the participants.

Table 3.8: Institutional indicators tested in the questionnaire.

Institutional indicators	Related section in the research instrument
Environmental legislations	Section C: Question 15
Waste management legislations	Section C: Question 13
Environmental impact	Section C: Question 14

Section C will cover the institutional indicators of the W.R.O.S.E model and the importance of e-waste recycling. Questions 13 and 14 explore the participant's awareness of legislation regarding e-waste disposal. Question 15 investigates the participant's awareness of the harmful impacts e-waste has on the environment (as shown in table 3.9). Question 16 explores the health risk associated with electronic waste Question 17 explores the perception of value in e-waste.

Table 3.9: Social indicators tested in the questionnaire.

Social indicators	Related section in the research instrument
Public participation	Section B: Question 7,8 & 12
Health risk (at varies life stages)	Section C: Question 16
Public participation in waste management	Section C: Question 13
Public participation in waste collection	Section C: Question 17

The respondents were given options when completing the questionnaire, as this will reduce the overall time to complete the questionnaire. The multiple-choice questions induced a higher response rate from participants. The questionnaires are to be hand-delivered to participants in facilities located within the study area. The questionnaires were addressed to the Information Technology Manager or the computer laboratory Manager in each facility. The reason for choosing these personnel to answer the questionnaire is that they were more familiar with each respective facility.

3.16 Selection of waste management strategies

The W.R.O.S.E model has been developed by UKZN (Trois and Jagath, 2010) to simulate several waste management strategies designed to prioritise the utilisation of waste as a resource. Various waste management strategies were previously used in studies using the W.R.O.S.E model were assessed according to their environmental impact, economic feasibility, social implementation ability and institutional and technical feasibility (Reddy, 2016). These strategies were altered to be used for the management of electronic waste streams. These strategies presented in Table 3.10 would then be implemented together to form several waste management scenarios.

Table 3.10: Waste management strategy summary (Trois & Kissoon, 2016, Reddy et.al 2016)

Waste management strategy	Evaluation criteria			
	Environmental impacts	**Economic feasibility**	**Social implementation**	**Technological feasibility**
Source separation	Initial separation reduces contamination of other wastes and hence increases the quality of the recyclables.	Economic impact of separate bins, refuse bags and collection services.	Public participation required, along with separate bins and refuse bags. Monthly collection services will be required.	Technically feasible as source separation of paper, aluminium and glass is used in most areas of eThekwini.
Drop off centre	Initial separation reduces contamination of other wastes and hence increases the quality of the recyclables.	Reduces MSW stream volumes, collection charges are omitted.	Public participation is Required for the Separation of waste, and the transportation of waste to drop off centres.	Technically feasible as drop off centres for other recyclables are active in the eThekwini municipality.
Material recovery facility (MRF)	A dirty MRF will be used as waste is mixed and unsorted. A MRF will separate only a fraction of e-waste, and a significant portion will still be disposed into landfills.	A dirty MRF capital and operating costs are relatively low compared to a clean MRF.	No public participation is needed if unsorted, untreated waste is used in MRF.	Technically feasible as MRF is currently operated in eThekwini for MSW, adjustments can be made for e-waste.
Landfilling	Negative impact to the environment. Toxic leachate can be released to surroundings, and nearby water bodies.	No addition capital required as, it is the current disposal strategy in SA.	No public participation needed, as normal unsorted waste can be used.	Current disposal strategy in majority of SA.

Recycling	Preserves natural resources. Increases carbon sequestration.	Recycled material sold at significant cost compared to virgin material.	Public participation will be required if source separation is used. No public participation will be needed if a dirty MRF is used.	Incentives to strengthen recycling market. Recycling centres and programs in place currently.
Recycling A: Pre-treatment	e-waste that cannot be recycled will be disposed into a landfill; these materials can have adverse effects on the environment.	Pre-treatment can be labour intensive; however, the recovery of recyclable can cover this cost.	-	Pre-treatment is widely adopted already in south Africa and for most electronic doesn't require skilled labour.
Recycling B: Pyrometallurgy	Pyrolysis can generate a significant volume of GhG.	Pyrolysis can be expensive, start-up cost.	-	Pyrolysis is a relatively simple technology and is already in practice in South Africa.
Recycling C: hydrometallurgy	Hydrolysis does not produce any greenhouse gas emissions; however, a significant volume of acid is produced.	Hydrolysis can be an economical solution if administered correctly.	-	In recent years, hydrometallurgical solutions have been used more often, technologies appear to be ready.
Refurbishment/reuse	Reduces the need for new electronics to be manufactured, reduce the GHG and less virgin materials will be consumed.	The reuse and redistribution of electronic devices can be economical, as the initial cost of obtaining electronic is omitted.	Some public participation is required in the redistribution of electronics.	Repairs can be simply or complex and varies with each situation.

3.17 Development of electronic waste management scenarios

The strategies for creating the integrated waste management plan were adopted from the W.R.O.S.E model (see appendix A) and amended for e-waste management at UKZN. These adapted scenarios are:

1. Scenario 1: Unsorted e-waste in the combined waste stream is collected by a contractor and is to be directly disposed of in a landfill.
2. Scenario 2: Unsorted e-waste in the combined waste stream is collected by a contractor, the contractor separates e-waste from the stream and sells it to a recycling agent.
3. Scenario 3: Source-separated e-waste, is sold to the contractor. The contractor refurbishes the functioning electronics and sells to a resale agent. The contractor sells the non-functioning electronics to a recycler.
4. Scenario 4: Source-separated e-waste. The functioning e-waste is be refurbished by UKZN and be reused internally or by another government agent. The non-functioning e-waste is to be sold by the contractor to a recycling agent.

3.17.1 Scenario 1: Unsorted e-waste in the combined waste stream is collected by a contractor and is to be directly disposed of in a landfill.

Scenario 1, figure 3.3, represents the status quo of waste disposal (Including e-waste), in South Africa. In scenario 1, the e-waste at UKZN is mixed in with the regular waste stream and is collected by a contractor. UKZN pay the contractor for the waste collection. The contractor disposes of the waste into a landfill site. Scenario 1 provides a baseline to compare the efficiency of the other scenarios.

Figure 3.3: Scenario 1 (Landfilling)

13.17.2 Scenario 2: Unsorted e-waste in the combined waste stream is collected by a contractor, the contractor separates e-waste from the stream and sells it to a recycling agent.

In scenario 2, as shown in figure 3.4, unsorted e-waste is collected by a contractor. UKZN pay for the waste collection. The contractor separates e-waste from the waste stream and sells it to a recycling agent. The remainder of the waste is to be disposed into a landfill site.

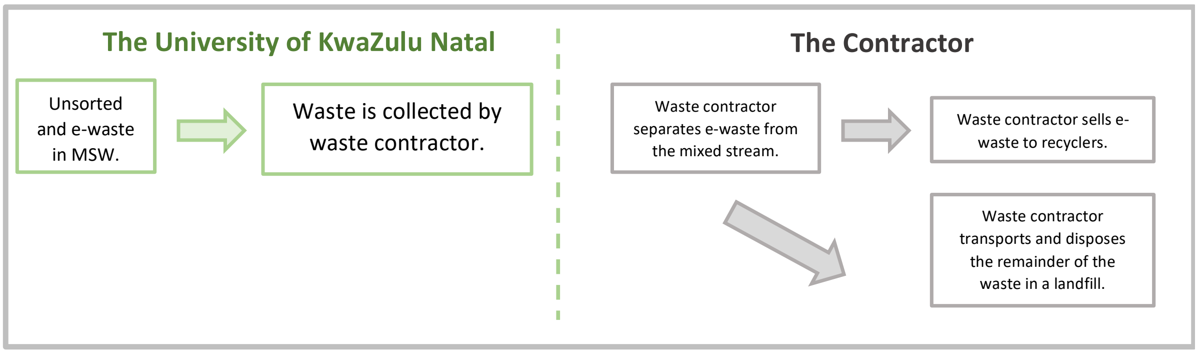


Figure 3.4: Scenario 2 (Recycling of e-waste)

3.17.3 Scenario 3: Source separated e-waste, is sold to the contractor. The contractor refurbishes the functioning electronics and sells to resale agent. The contractor sells the non-functioning electronics to a recycler.

In scenario 3, as shown in figure 3.5, a holistic, integrated waste management solution is adopted. The e-waste is to be separated at the source and be divided based on functionality. The e-waste is to be source-separated at UKZN and then sold to the contractors.

The contractors are to refurbish the functioning electronics and sell to a resale agent. The electronics that are functioning are to be refurbished and reused, as a large part of South Africa does not have access to technology, and they will benefit from access to more affordable electronics.

The non-functioning e-waste will be sold by the contractor to a recycling agent. Most recyclers in South Africa do not have the capacity to recycle metals and plastics, therefore the recyclables are only extracted by recyclers and sold to smelters and to remanufacturers (see chapter 2.14).

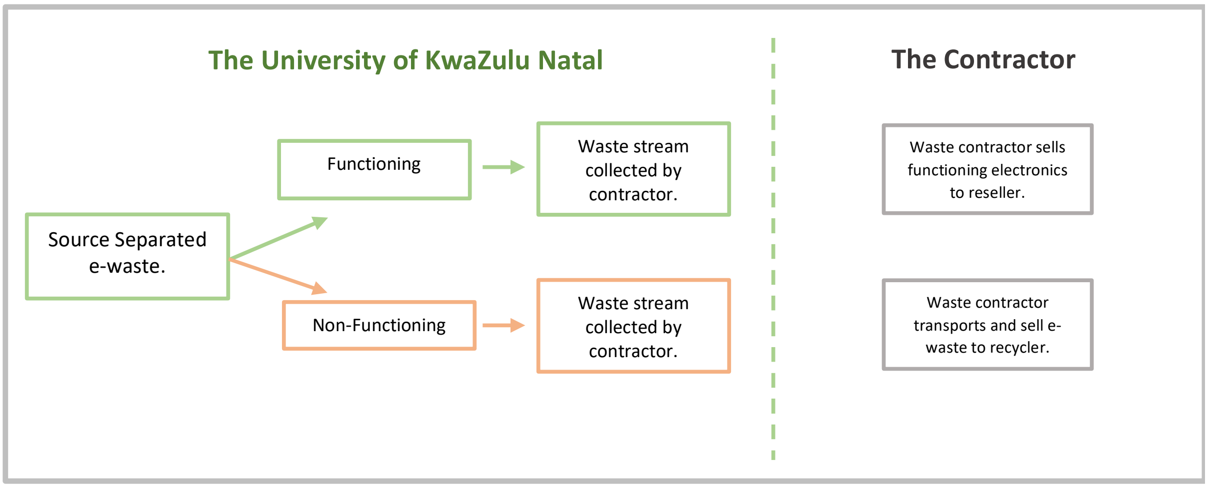


Figure 3.5: Scenario 3 recycling and reuse

3.17.4 Source separated e-waste. The functioning e-waste to be refurbished by UKZN and be reused internally or by another government agent. The non-functioning e-waste is to be sold by the contractor to a recycling agent.

In scenario 4 similar to scenario 3 (as shown in figure 3.5), a holistic, integrated waste management solution is adopted. The e-waste is to be separated at the source and be divided based on functionality. The e-waste is to be source-separated at UKZN, and the non-functioning fraction is sold to the contractors.

The non-functioning e-waste will be sold by the contractor to a recycling agent. Most recyclers in South Africa do not have the capacity to recycle metals and plastics, therefore the recyclables are only extracted by recyclers and sold smelters and to remanufacturers (see chapter 2.14).

The functioning electronics are to be refurbished, the functioning electronics are to be reused internally by UKZN or by another government agent. The electronics that are functioning are to be refurbished and reused, as a large part of South Africa does not have access to technology, and they will benefit from access to more affordable electronics.

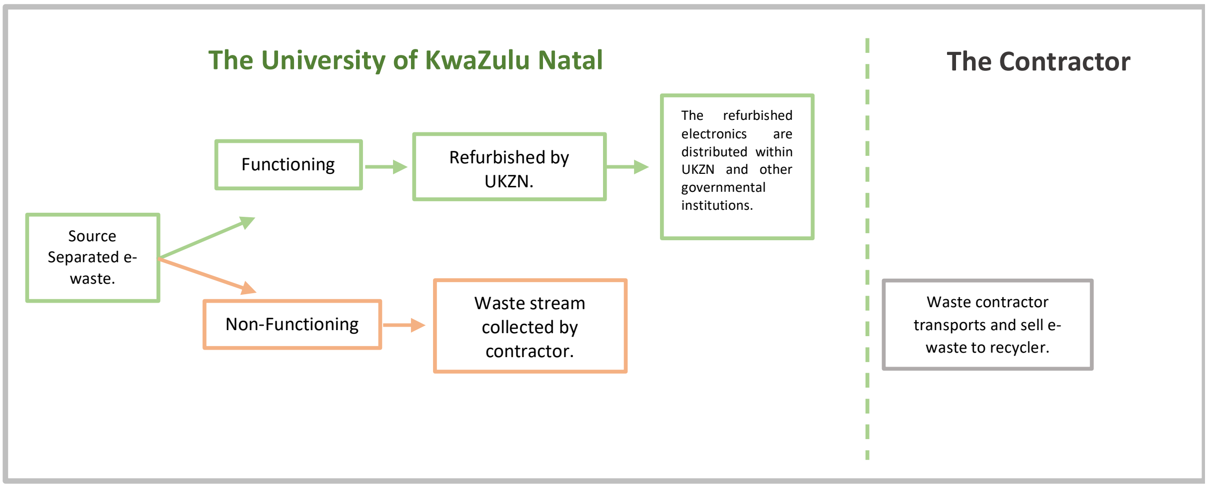


Figure 3.6: Scenario 4 Recycling and reuse

3.18 Potential indicators in the W.R.O.S.E model

The following criteria were adopted from previous studies that employed the W.R.O.S.E model as a scenario analyser (Reddy, 2016; Trois & Kissoon, 2020). In table 3.11 the environmental indicators are discussed, the indicators selected are based on a previous study conducted using the W.R.O.S.E Model.

Table 3.11: Environmental indicators (Reddy,2016, Trois &Kissoon 2016)

Environmental indicators
Global warming potential (MTCO$_2$eq) – The amount of metric tons of greenhouse gases emitted (Carbon dioxide equivalent), through the various scenarios.
Landfill space savings (m^3) – The amount of waste saved through the diversion of waste.
Toxic potential (Varies) – The amount of heavy metals that can be realised from electron waste.
Water consumed (Litres) - The water that is consumed in each scenario.
Energy consumed (GJ/MW) – Energy used by the different scenarios.

The economic indicators are shown in table 3.12; the indicators selected are based on a previous study conducted using the W.R.O.S.E Model.

Table 3.12: Economic indicators (Reddy,2016, Trois &Kissoon 2016)

Economic indicators
Capital cost (Rand) - These are the fixed cost associated with each scenario.
Operating costs (Rand) – These are the variable costs associated with each scenario.
Income (Rand) – The potential revenue generated for sale of refurbished electronic equipment and form recycling activities.
Long term feasibility (Rand) – The long-term merit of the scenario, to assess whether recycling and refurbishing activities still be feasible in the future.
Sensitivity to variables (Rand) – Stability of the scenario when variables are changed.

The Social indicators are shown in table 3.13, the indicators selected are based on previous study conducted using the W.R.O.S.E Model.

Table 3.13: Social indicators (Reddy,2016, Trois &Kissoon 2016)

Social indicators
Job creation – The number of temporary and permeant jobs that will be created.
Public participation- The amount of public support that will be needed in each scenario, i.e., source separating.
Public acceptance – Perception of the people involved in each scenario (The stake holders)

3.19 Feasibility/ sustainability criteria

According to a study by Fiksel (2009) and Reddy (2016), the following criteria is to be used when choosing sustainability indicators. The set of indicators should be:

- Relevant: is the solution addressing the problems of the selected audience, and will it improve the way things are being done?
- Meaningful: to the intended audiences in terms of clarity, comprehensibility, and transparency?
- Comprehensive: does it align with sustainability goals and the SARCHI goals?
- Transferable: can the study be applied to different environments and at different scales?

- Practical: is the solution, cost-effective and easy to implement?
- Durable: will the solution last?

3.20 W.R.O.S.E assessment indicators

The W.R.O.S.E assessment indicators that will be used in the study are shown below. The quantities of waste, the economic feasibility and the environmental impacts of each scenario will be assessed using these indicators.

3.20.1 Toxic potential

The toxic potential of electronic waste is to be assessed, as the production of toxic leachates in landfills sites is a great concern. The materials that will be used to determine the toxic potential are largely heavy metals. The specific heavy metals that will be used are the most hazardous and highest concentrations, as shown in table 3.14. The complete material composition of the e-waste stream can be seen in appendix A, Table A6.

Table 3.14: Concentration of toxic material in common electronic devices.

Heavy metal	Desktop (g/unit)	Printer (g/unit)	Projectors (g/unit)	AC (g/unit)
1. Cadmium	3,6277E-05	0,26	0.0072	0.286
2. Chromium	3,63E-05	1.4145	0.0648	2.21
3. Copper	150.356	1550	0.576	2860
4. Lead	16.938	1.138	0.0082	5.2
5. Mercury	0.00015	0	0	0
6. Nickel	0.00885	0.062	0.0288	1.17
7. Zinc	0.0457	0.828	0.432	0.728
Reference	(Cucchiella, et al., 2015)	(Almutairi, et al., 2015)	(Almutairi, et al., 2015)	(Lydall, et al., 2017)

The PCB's contain the largest volumes of heavy and precious metals; therefore, these items' recovery must be prioritised. In appendix B3, the material composition of the PCB's is shown.

3.20.2 Landfilling

The most common method of e-waste management is disposal into a landfill site. Landfill disposal is the primary strategy in scenario 1 and is a supplementary strategy in scenarios 2, 3 and 4. The cost for the collection and disposal of waste is derived from the following assumptions based on past studies and municipal tariffs. The cost of landfilling is comprised of collection charges and gate fees. The collection charge is shown in table 3.15.

Table 3.15: Collection charge (Municipal tariff, 2020/2021)

Collection charge	Description	Charge per ton	Reference
Labour	3 labourers (Assume drivers and collectors at same rate)	R 100	Municipal tariff (2020/2021)
Diesel	Approximately 6 litres per hour, used current diesel price (May 2021)	R 96.2	Municipal tariff (2020/2021)
Truck	Truck maintenance/Rental	R 206.2	Assumed based on DSW data (2020/2021)
	Total Per ton	R 402.4	
Amount collected	Total volume that can be collected in a day	12 tons	Truck capacity

The gates fees are derived from the charges quoted from municipal landfills, the landfills that the waste from the University of Kwa-Zulu natal (UKZN) are shown in table 3.16.

Table 3.16: Gate Fee (Municipal tariff, 2020/2021)

UKZN Campus	Landfill	Gate fee per ton (2020/2021)
Howard	Bisasar road	R 420
PMB	Msunduzi	R 408.5
Westville	Bisasar road	R 420
Edgewood	Marrianhill	R 420
Medical	Bisasar road	R 420

3.20.3 Recycling

The strategy of recycling is used in scenarios 2, 3 and 4. The recycling scenario was assessed based on profitability (i.e., Profit = Revenue – Costs). The cost associated with recycling are fixed and variable (As shown in table 3.17). The data was obtained from interviews with e-waste recyclers (see Appendix B2, for a sample of the questions asked) in the eThekwini municipality, and the average cost of the three e-waste recyclers (as shown in appendix E6) was used in further calculations.

Table 3.17: Cost per ton (Appendix E6)

Type of cost		**Per Ton**	**Source**
Fixed cost	Equipment	R 125	E-waste recyclers (Table 3.17)
	Rent	R 125	E-waste recyclers
Variable	Labour	R 1 344	E-waste recyclers & Municipal guidelines
	Energy	R 288	E-waste recyclers
	Materials	R 50	E-waste recyclers
	Transport	R294,87	E-waste recyclers

The e-waste recyclers were chosen based on geography, experience and services provided (as shown in table 3.18).

Table 3.18: E-waste recyclers in Durban

Name of recycler	**Location**	**Description**
E-Waste tech It recycling	Westville	Medium (1 -2 tons a day)
Electronic cemetery	Hillcrest	Small scale (less than 500 Kg a day)
E-waste Africa	Durban central	Small scale (less than 500 Kg a day)

Most of the recyclable fraction is easily extracted from the e-waste, except for the PCB's. There is two distinct type of material extraction used on PCB's, namely pyrolysis and hydrolysis. In table 3.19, the available types of metal extraction in Kwa-Zulu Natal are shown.

Table 3.19: Types of material extraction

Name of recycler	Pyrolysis (Incineration)	Pyrolysis (Smelting)	Hydrolysis
E-Waste tech It recycling	Yes	No	Yes
Electronic cemetery	Yes	No	No
E-waste Africa	Yes	No	Yes

In scenario 1 there is no potential for revenue, however, in scenarios 2,3 and 4, there are three potential sources of revenue. In scenario 2, 3 and 4, once the recyclables are separated from the e-waste it is to be resold to smelter and remanufacturers.

At present (2020) the majority of South African e-waste recyclers do not charge a customer fee for the collection and recycling of e-waste. The revenue obtained from e-waste recycling is dependent on the waste stream, therefore a specific analysis is required. In table 3.20, the potential revenue sources are shown.

Table 3.20: Potential revenue sources

Revenue source	Description	Source
Material recovery	The material recovered from recycling operations is to be sold to generate revenue	See Appendix E
Customer fee	None, (collection and recycling are free).	E-waste recyclers (Appendix E)

3.20.4 Resale of components

In scenarios 3 and 4, the functioning electronic components are to be refurbished and resold. Upon consultation with key members of the UKZN staff (i.e., CMS officials), at present, the university does not sell any of its e-waste. Rather, they opt to donate the functioning electronics to various other institutes. However, only a small fraction is donated (approximately 10-12%). The UKZN Staff and decision-makers are open to the resale of exhausted electronics, upon a feasibility study that will ensure this strategy is economically feasible and sustainable.

The resale potential of discarded electronic devices is based on physical condition. The discarded electronic devices are assessed based on the individual model; therefore, it would be difficult for an e-waste recycler to quote a price. Therefore, the resale value must be assessed based on market prices and consumer behaviour. The resale value was determined from three second-hand resellers; the resellers are shown in Table 3.21.

Table 3.21: Certified Resellers

Reseller	Location	Description
Africa PC	Westville	Medium scale reseller
Refurb. SA	Hillcrest	Small scale reseller
Just PC's	Durban North	Small scale reseller

The electronic devices that has the highest resale value are Printer/Photocopiers while the Projector unit's resale for the lowest amount. The resale value of the electronic depending on the condition of the device is shown in Table 3.22. Table 3.20 is a summary of the data shown in appendix E, table E1.

Table 3.22: Resale value

Condition	Low quality	Moderate	Excellent
Desktops	R 1 200	R 4 000	R 5 000
Projectors	R 600	R 2 000	R 3 500
Air conditioning units	R 800	R 3 000	R 4 000
Printers	R 5 000	R 16 000	R 22 000

According to Africa PC and Refurb SA, approximately 1 job (temporary) can be created for each ton of electronic to be resold.

3.20.5 Emissions

There are two types of emissions air/gas emissions and liquid emissions that originate from waste. Electronic waste does not naturally emit any gaseous (Except HFC's, which have been phased out of most electronics), therefore the air emissions that will be used in this research will only be transport and recycling emissions (as shown in table 3.23).

Table 3.23: Summary of Emissions per ton

Source	Description	CO (Kg)	CO2 (KG)	CH3 (Kg)	Sources
Transport	Collection from low density urban areas	-	40,3	-	Friedrich, Trois (2013)
Transport	Collection from High density urban areas	-	8,9	-	Friedrich, Trois (2013)

Recycling	Recycling by pyrometallurgy	16	15 000	18 000	Summary of Chapter 2.10.1
Recycling	Recycling by hydrometallurgy	n/a	n/a	n/a	n/a

The second type of emission that is discharged from e-waste is liquid emissions in the form of toxic leachate. The leachate is formed when the organic waste saturates electronic waste in landfills and by rainfall. Therefore, the volume of toxic leachate produced depends on the size of the landfill and the climate conditions. The waste from the five campuses in the study goes to three landfills, namely Bisasar road, Mariannhill and new England landfill (as shown in table 3.24). In table 3.23, the climate and the landfill site sizes can be seen.

Table 3.24: The landfill sites

Landfill	Landfill size	Climate	Source
eThekwini: Bisasar road	Relatively large landfill site 3500 tons per day, 44 hectares' space available.	Moderate rainfall (925mm), occasionally heavy rainfalls. (Flood 1/50 years)	Municipal records/weather reports
eThekwini: Marian hill	Relatively large landfill site 2500 tons per day, 30 hectares' space available	Moderate rainfall (925mm), occasionally heavy rainfalls. (Flood 1/50 years)	Municipal records/weather reports
Msunduzi: New England		Moderate rainfall (897mm), occasionally heavy rainfalls. (Flood 1/50 years)	Municipal records/weather reports

The data from table 3.24, illustrated that the landfill sites in the study area are on a relatively large scale. In combination with the occasionally heavy rainfalls, this creates a suitable environment for toxic leachate to be produced. A study by (Xu, et al., 2018) discovered that in ideal conditions (Heavy rainfall, in a large landfill site) over 90% of the toxic material in e-waste were leached. Using this study's finding, we can approximate that between 60-80% of toxic material can be potentially leached in the study area.

3.20.6 Landfill space saving

The landfill space-saving will be measured by analysing the volume of e-waste that is diverted from the waste stream. A study by Chung (2018), illustrated that electronic devices are becoming more compacted and denser (as shown in figure 3.7). Therefore, minimal compaction of the e-waste will occur in the landfill site. Therefore, this study will assume that e-waste will not be compacted, and the nominal volume will be used for further calculations, i.e., 1 ton = 1 m^3.

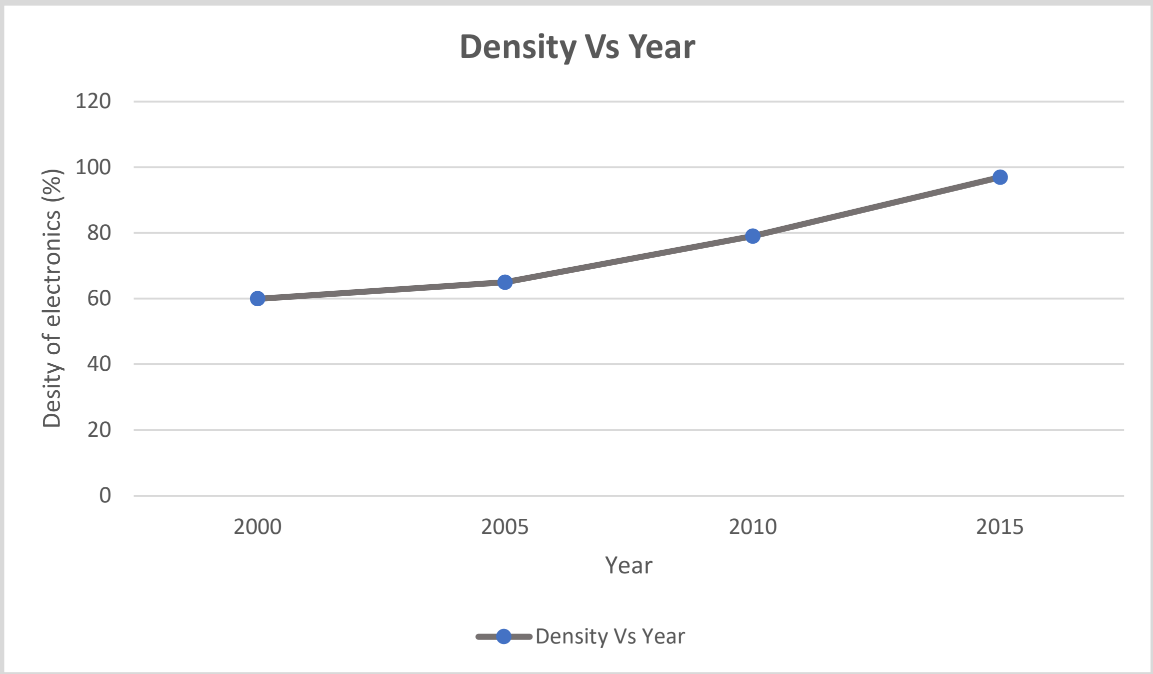


Figure 3.7: Density of electronics (Chung, 2018)

3.21 Validation

According to Reddy (2016), the validity of the W.R.O.S.E model is derived from the waste management strategies and indicators, that are used in its application. The key factors are based on multiple sets of real-life data as a base (i.e., Transport cost, Recycling cost and Resale value).

According to Reddy (2016), the second level of validation is in how these factors are applied. Each waste management strategy has an individual waste emission factor, capital costs, and revenue generated with a specific application method.

Furthermore, waste emission factors are continually changing due to the ever-evolving world we live in; this results in the need to continually update emission factors in WROSE as a validation method (Reddy,2016). The W.R.O.S.E model uses multiple sets of raw data, which is allowed to be updated and modified based on different environments, which gives the W.R.O.S.E. model a grass root level of validation.

Assumptions

The W.R.O.S.E model has factors implemented based on various assumptions; these are:

- The material recovery facility capital and operating costs are assumed based on both historic data and past studies.
- The emission factors are assumed to be applicable to South Africa but are derived from international factors.
- The recycling rates are assumed to be applicable to South Africa but are derived from international factors.

Chapter summary

This chapter discussed the design methodology to be used to obtain the desired results, and the ethical responsibility needed to produce credible research. In the next chapter, the results of the survey are presented, analysed, and discussed.

Chapter 4: Pilot study

According to Nashwa et al., (2018), a pilot study is performed to test the research instrument, particularly to test its ability to obtain the required information. The pilot study was critical in this study in particular, due to the global pandemic of 2020. The pilot study was conducted at the University of Kwa-Zulu Natal's Howard campus. The data from the research instrument will be analysed, and based on the results, the necessary amendments and corrections will be made.

4.1. Aim and objectives of the Pilot study.

The pilot study aims to test the research instrument/experiment and determine if the necessary information can be obtained.

The objectives of the pilot study are to:

- Identify the electronic waste stream, identify which areas contribute the highest volumes of e-waste.
- To explore how will the Covid-19 restrictions affect the research.
- To identify any shortcomings or misunderstandings of the research instrument.

4.2. The research designs.

The pilot test was conducted at UKZN's centenary building, the home of the civil engineering program. This area was selected because it contains all three types of study areas. The Centenary building contains three LAN buildings, ten staff and administration offices, and four lecture venues that qualified it for the test. The test was undertaken in the area, as mentioned above, and the feedback was assessed. The questionnaire required minor alterations, three questions were rephrased, and one question was omitted as it was not directly relevant to the study.

Table 4.1: Summary of Methodology

Who?	University of Kwa-Zulu Natal (UKZN)
When?	5th March to 27th March 2020
Where?	UKZN Howard campus (Centenary building).
Why?	To test the research instrument.
Way?	Use of a structured questionnaire (See appendix b1).

4.3. Target population and sample size

The Centenary building at UKZN's Howard's campus was selected for the pilot study. This area was selected because it contains all three types of study areas. The Centenary building contains 3 computer laboratories, 10 offices and 8 lecture venues. There are a total of 21 samples available at the centenary building, which according to Whitehead et. al (2015) means is suitable for the pilot study. The questionnaire will be distributed to each of the staff members responsible for the respective facilities.

Upon consultation with UKZN representatives (Informal meeting with ICS management), it was determined that the layout of the computer laboratory, lecture venues and offices spaces are very similar in design. The Centenary building at UKZN Howard contains the following number of locations:

Table 4.2: Sample Size of Centenary building

Computer Laboratory	Lecture venues	Offices
3	8	10

Therefore, it is a fair representation of the sample, and it will provide significant data to calibrate the research instrument.

4.4. The results and discussion

The pilot study results were analysed, and the results (As shown in appendix C) from section A (Quantities of e-waste) can be seen in figure 4.1. The largest volume of e-waste originated from computer laboratories, followed by lecture venues then offices. The results of the pilot study discovered that most of the e-waste came from 4 items, Desktop computers, printers, projectors, and air conditioning units. Therefore, for the purposes of these are the only items used in the study.

The computer laboratories contributed 90% of all Desktop PCs, 100 % of the printers, 30% of the projectors and 60% of the Air conditioning units. In comparison to the computer laboratories, the lecture venues and offices did not generate a significant volume of e-waste. The highest contributors to e-waste in terms of volume are desktop computers (14,5 Kg), printers (34,5 Kg) and Air conditioning units (26 Kg). In comparison, projector units (3,6kg) contribute significantly less and other non-common items (TV's, fridges and stoves).

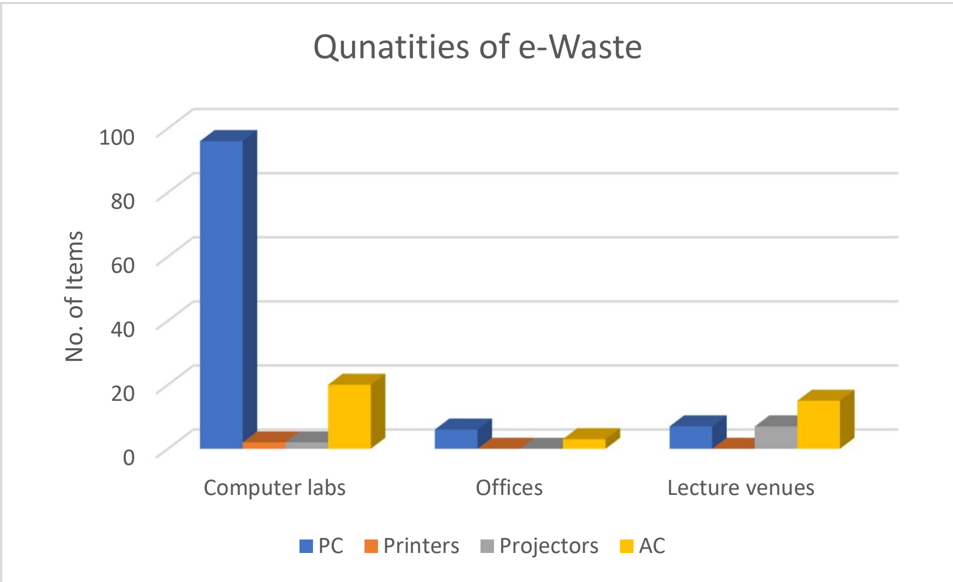


Figure 4.1: E-waste quantity at Centenary building (UKZN, Howard)

The results from sections B and C of the research instrument are shown in table 4.3 and 4.4 respectively. The results were similar for all three study areas, with minimal deviations between the computer laboratories, lecture venues and offices. It is fair to assume that the social and environmental influences of e-waste management are not dependent on the type of area (this assumption is only for the study).

Table 4.3: Research instrument social influences

Section B: Questions	Most popular response		
	Computer laboratories	Lecture venues	Offices
4. How often are electronics upgraded or replaced in your organisation?	C (100%) (4-5 years)	C (100%)	C (100%)
5. To what extent do you agree or disagree with the statement that "there is limited information available on electronic waste management	E (100%) (Strongly agree)	E (100%)	E (72%)
6. Does your organisation currently store or gets rid of obsolete/redundant electronic and electrical equipment?	A (100%) (Store waste)	A (100%)	A (72 %)
7. If your organisation stores and does not get rid of your electronic and electrical equipment, where does your organisation store this obsolete or redundant equipment?	A (100%) (On-site)	A (100%)	A (72%)
8. Which of the following can be a reason for not disposing obsolete electronic equipment?	A (100%) (We are not aware of any authorised agent that will recycle our e-waste)	A (100%)	A (72%)
9. How does your organisation dispose of its obsolete/redundant electronic and electrical equipment? (CMS)	A (100%) (Treat it as ordinary office bin/municipal waste	A (100%)	A (72%)
10. To what extent do you agree or disagree with the statement that "it is important for organisations to have a strategy for the management of obsolete/redundant electronic and electrical equipment"?	D (100%) (Agree)	D (100%)	D (72%)

Table 4.4: Section C environmental influences

Section C: Questions	Most popular response		
	Computer laboratories	Lecture venues	Offices
11. Are you aware of any legislation that deals with the disposal of obsolete/redundant electronic and electrical equipment?	A (66%) (Yes)	A (80%)	A (72%)
12. Are you aware of any environmental legislations regarding electronic waste?	C (66%) (Disagree)	C (80%)	C (72%)
13. To what extent do you agree or disagree with the statement that "obsolete/redundant electronic and electrical equipment contains harmful substances to the environment"?	A (66%)	A (80%)	A (72%)
14. Are you aware of the health risks associated with electronic waste?	A (66%) (Yes)	A (80%)	A (72%)
15. To what extent do you agree or disagree with the statement that "obsolete/redundant electronic and electrical equipment contains no value"?	A (66%) (Strongly disagree)	A (80%)	A (72%)

4.5. Amendments to the study

The research instrument will now be amended based on the above information, and the Covid-19 restrictions experienced during the pilot study.

The majority of the e-waste originates from computer laboratories (90%); therefore, the research experiment should be altered by removing the lecture venues and offices. A more specified (smaller) study area will be greatly beneficial to the study, as both time restraints and time required to analyse data from a larger area are significantly more difficult.

Section B and C of the questionnaire yielded similar results, promoting the exclusion of the lecture venues and offices from the study, as there will be no unique or exceptional information obtained from these areas.

A smaller study area will reduce the sample size, which means fewer interactions with participants, therefore adhering to Covid-19 restrictions. Due to the Covid-19 restrictions, face to face contact must be minimised, the research instrument (which is a structured questionnaire), must be attempted to be administered through non-contact methods (such as email or phone call). Therefore, the reduced sample size is favourable to completing the research. There are approximately 90 computer laboratories across all five campuses, as the majority of e-waste originate from these facilities the data obtained will yield significant results.

The pilot study did expose some shortcomings in the research instrument; participants report that it took too long to complete and that some question was ambiguous (Question 12 and 14). Amendments must be made going forward.

Chapter 5: Analysis of Research Instrument

In this chapter, the questionnaire results were analysed to create a criterion in which the integrated waste management plan (IWMP) is created.

5.1. Research questionnaire: Section A (Quantities of e-waste)

In this section, the volumes of electronic waste generated across the five campuses will be evaluated. The average life span, the reason for the disposal of electronics, and the electronic quality upon disposal. The detailed methodology of how the data from the questionnaire (Section A) was analyses to obtain the potential volume of e-waste can be found in Appendix D.

5.1.1. Howard campus

The structured questionnaire was analysed to obtain the potential volume of e-waste. The University of Kwa-Zulu Natal's Howard campus produces a significant amount of electronic waste. At Howard campus, there were 42 research questionnaires administered to the staff members responsible for the respective facilities (See Appendix D.1.1); the analysed results are shown below. The potential electronic waste generated is shown in figure 5.1. The Howard campus consists of 1589 desktops computers, 120 printers/photocopiers, 136 air conditioning units and 23 projectors.

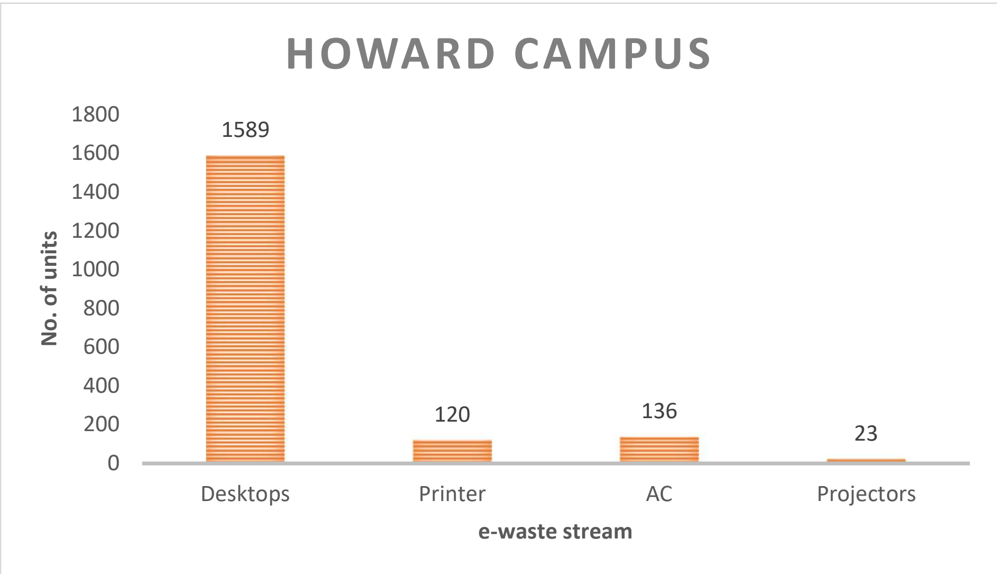


Figure 5.1: Howard campus e-waste generation

The most significant fraction of e-waste that originates from Howard campus is desktop computers (85%). This is followed by air conditioning units (7%) and printer/photocopiers (6%) with projectors (1%) contributing the least (as shown in figure 5.2).

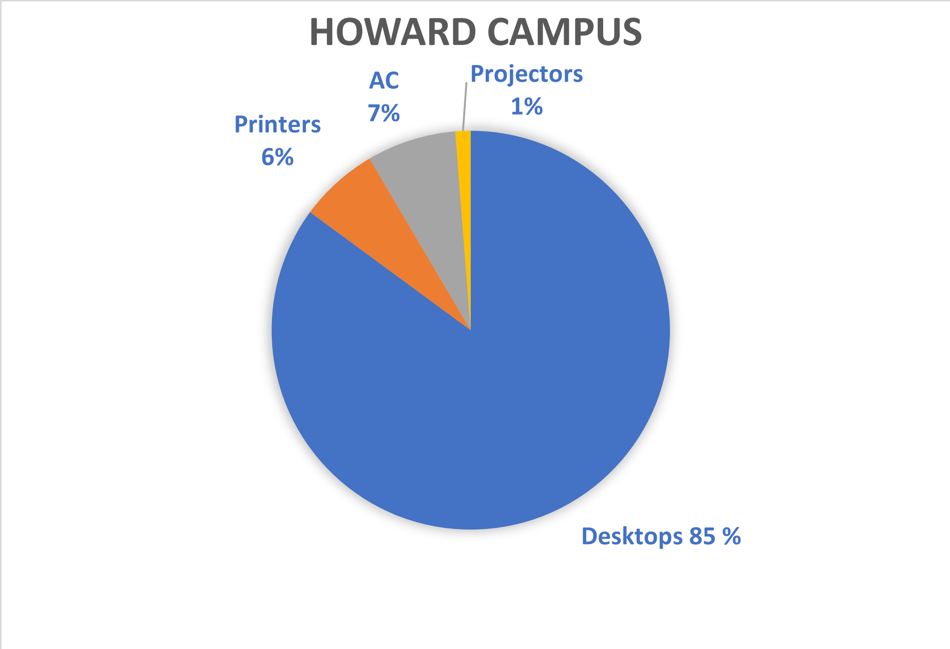


Figure 5.2: Howard campus e-waste stream composition

5.1.2. Westville campus

The structured questionnaire was analysed to obtain the potential volume of e-waste. The University of Kwa-Zulu Natal's Westville campus produces a significant amount of electronic waste. (Compared to an average campus). At the Westville campus, there were 16 research questionnaires administered to the staff members responsible for the respective facilities; the analysed results are shown below. The potential electronic waste generated is shown in figure 5.3. The Westville campus consists of 823 desktops computers, 20 printers/photocopiers, 55 air conditioning units and 9 projectors.

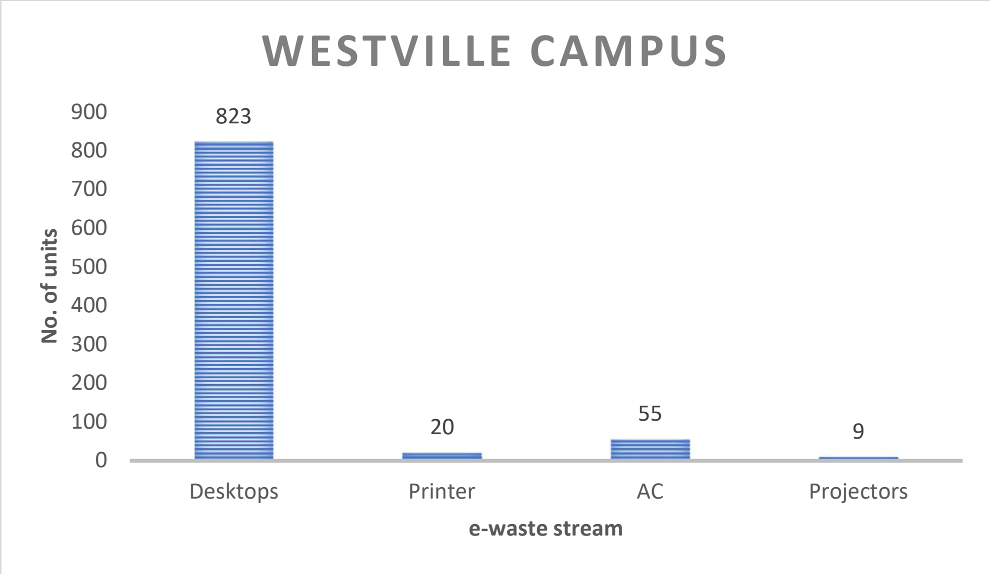


Figure 5.3: Westville campus e-waste stream

The most significant fraction of e-waste that originates from the Westville campus is desktop computers (91%), followed by air conditioning units (6%) and printer/photocopiers (2%) with projectors (1%) contributing the least (as shown in figure 5.4).

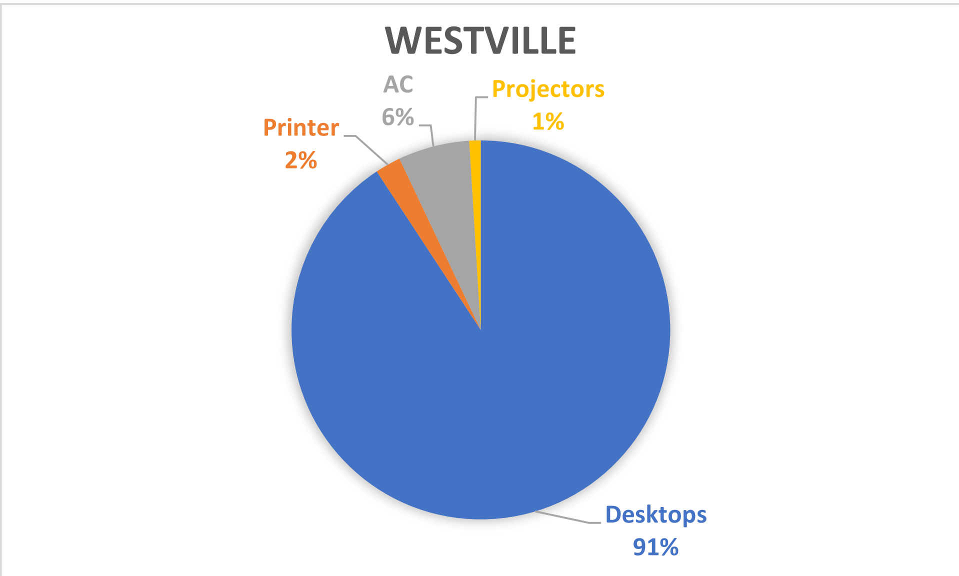


Figure 5.4.: Westville campus e-waste stream composition

5.1.3. Medical school campus

The structured questionnaire was analysed to obtain the potential volume of e-waste. The University of Kwa-Zulu Natal's medical school campus, produces a significant volume of electronic waste. At the medical school campus there were 3 research questionnaires administered to the staff members responsible for the respective facilities, the results are shown below. The potential electronic waste generated is shown in figure 5.5. The medical school campus consists of 206 desktops computers, 11 printers/photocopiers, 28 air conditioning units and 9 projectors.

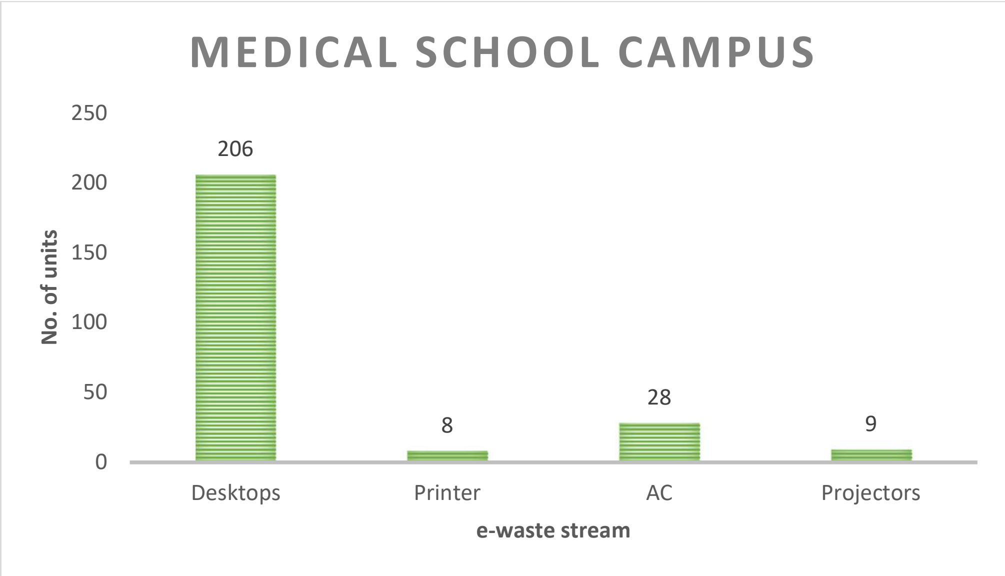


Figure 5.5: Medical school campus generation

The most significant fraction of e-waste originating from the medical school campus is desktop computers (82%). This is followed by air conditioning units (11%) and printer/photocopiers (2%) with projectors (4%) contributing the least (as shown in figure 5.6).

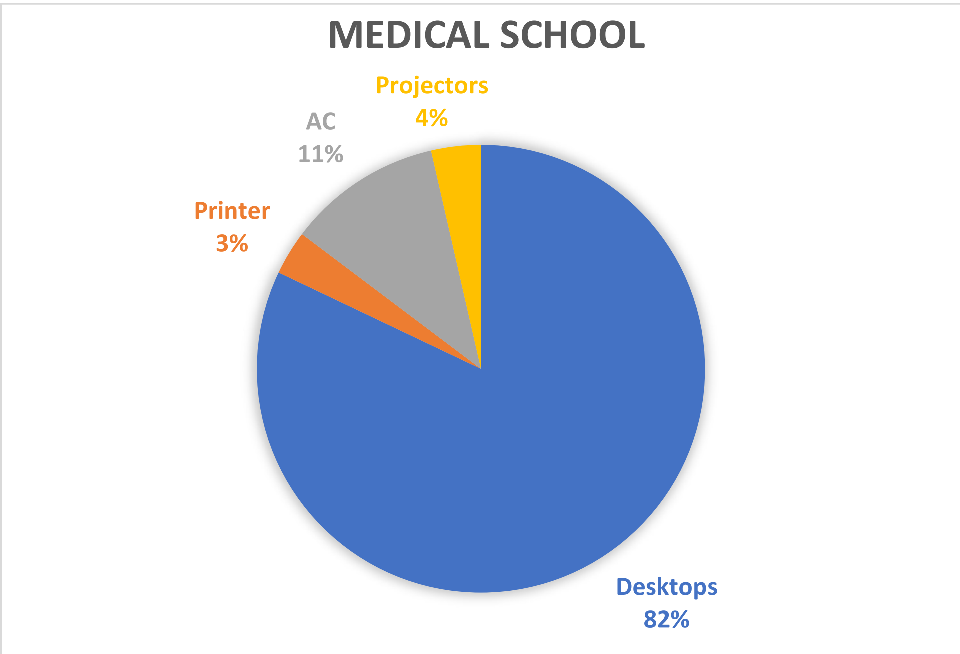


Figure 5.6: Medical school campus e-waste stream composition

5.1.4. PMB campus

The structured questionnaire was analysed to obtain the potential volume of e-waste. The University of Kwa-Zulu Natal's PMB campus produces a significant amount of electronic waste. At the PMB Campus, there were 23 research questionnaires administered to the staff members responsible for the respective facilities, the analysed data are shown below. The potential electronic waste generated is shown in figure 5.7. The Howard campus consists of 636 desktops computers, 11 printers/photocopiers, 50 air conditioning units and 12 projectors.

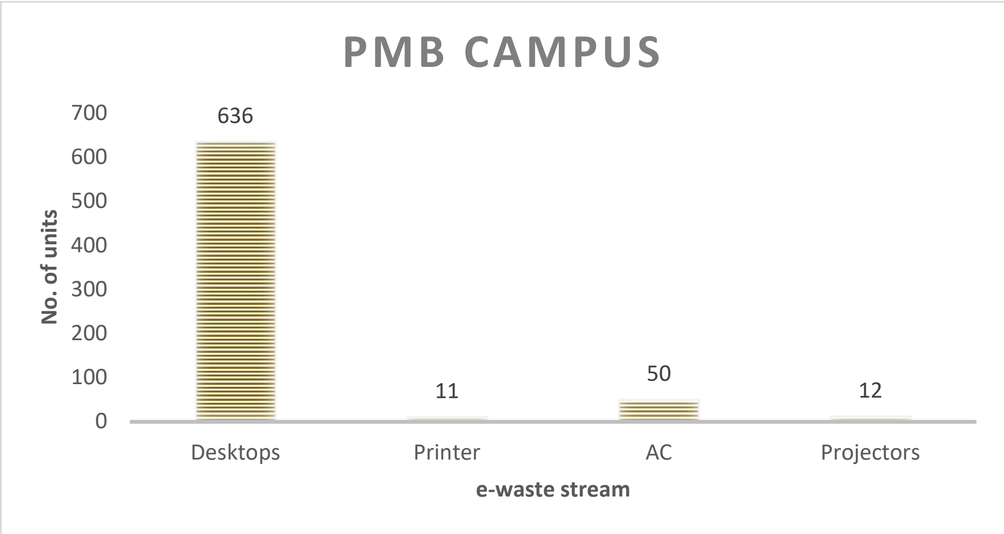


Figure 5.7: PMB campus generation

The most significant fraction e-waste that originates from the PMB campus is desktop computers (90%). This is followed by air conditioning units (7%) and printer/photocopiers (2%) with projectors (2%) contributing the least (as shown in figure 5.8).

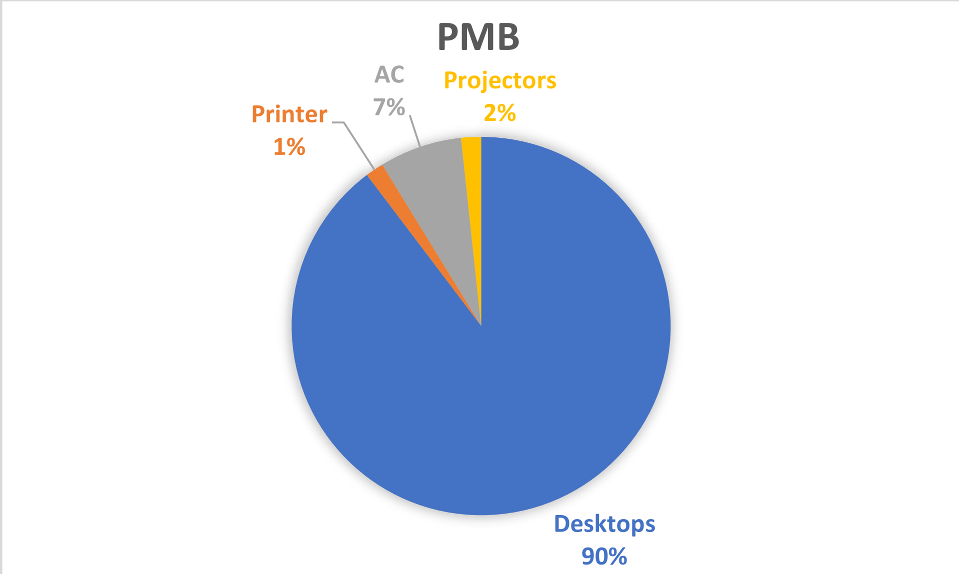


Figure 5.8: PMB campus e-waste stream composition

5.1.5. Edgewood campus

The structured questionnaire was analysed to obtain the potential volume of e-waste. The University of Kwa-Zulu Natal's PMB campus produces a significant amount of electronic waste. There were 11 research questionnaires administered to the staff members responsible for the respective facilities at the Edgewood Campus, the analysed results are shown in figure 5.9. The potential electronic waste generated is shown in figure 5.9. The Edgewood campus consists of 405 desktops computers, 9 printers/photocopiers, 45 air conditioning units and 7 projectors.

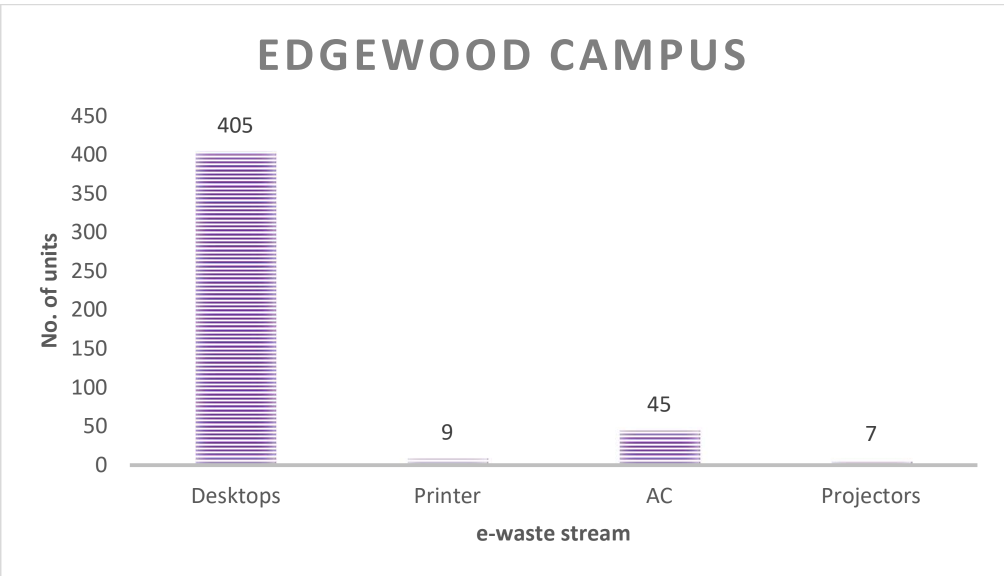


Figure 5.9: Edgewood campus generation

The most significant fraction of e-waste that originates from the Edgewood campus is desktop computers (90%), followed by air conditioning units (7%) and printer/photocopiers (2%) with projectors (2%) contributing the least.

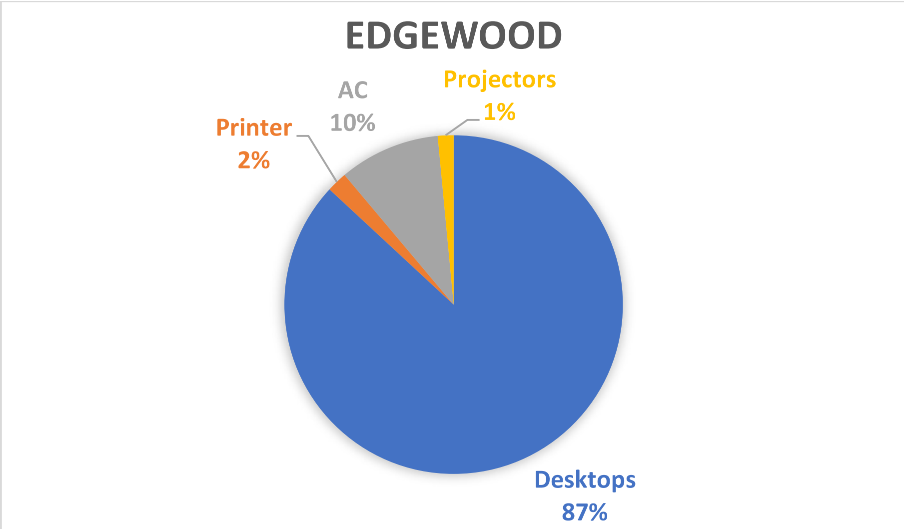


Figure 5.10: Edgewood campus e-waste stream composition

5.1.6. Lifespan of electronic devices

The study participants were asked to estimate how often electronic devices are replaced in their organisation, which was used to determine the approximate lifespan of the electronic devices.

The research instrument (Section A, Question 7) was analysed to determine the average lifespan of electronics at the University of Kwa-Zulu Natal. In table 5.1, the most common responses are shown. The conclusion drawn from table 5.1 is that the average time that electronics are used at the University of Kwa-Zulu Natal is between 4-5 years. For further calculation, the conservative 5-year lifespan will be used.

Table 5.1: Lifespan of electronic devices

Question 7	**Howard campus**	**Westville campus**	**Medical school campus**	**PMB campus**	**Edgewood campus**
	4-5 years 42 Responses (100%)	4-5 years 16 Responses (100%)	4-5 years 3 Responses (100%)	4-5 years 23 Responses (100%)	4-5 years 11 Responses (100%)

According to a study by Kaya (2019), the estimated planned obsolesce (lifespan) of desktop computers are 6 years. While printers/photocopiers are 8 years, projectors are 10 years, and air conditioning units are 12 years. Therefore, the electronic devices at UKZN upon disposal still have a significant useable lifespan.

5.1.7. The summary of the total e-waste generated.

The data from the research instrument (as shown in appendix D) is summarised in table 5.2 and table 5.3. The total electronic waste generated from the University of Kwa-Zulu natal campuses is shown in table 5.2.

Table 5.2: Summary of e-waste generated at each campus.

	Howard campus	**Westville campus**	**Medical school campus**	**PMB campus**	**Edgewood campus**	**Total**
Desktop (Kg)	23040	11933.5	2987	9222	5872.5	56 977.75
Printers/ Photocopier (Kg)	4140	690	276	379.5	310.5	5865
Air Conditioning units (Kg)	3536	1430	728	1300	1170	8281
Projectors (Kg)	82.8	32.4	14.4	43.2	234	158.4
Total (kg)	30 779.5	11 205.9	14 085.9	11 205.9	4005.4	

The annual e-waste generated at the various campuses of the University of Kwa-Zulu Natal is shown in table 5.3. The annual e-waste generation are calculated by dividing the total e-waste generation by the average lifespan (see appendix E1).

Table 5.3: Annual e-waste generated at each campus.

	Howard campus	Westville campus	Medical school campus	PMB campus	Edgewood campus	Total (Kg)
Desktop (Kg)	4608.1	2386.7	597.4	1844.4	1174.5	10 611.1
Printers/ Photocopier (Kg)	828	138	55.2	75.9	62.1	1 159
Air Conditioning units (Kg)	707.2	286	145.8	260	234	1633
Projectors (Kg)	16.56	6.5	2.88	8.64	5.04	39.62
Total (Kg)	6159.86	2817.2	801.23	2188.94	1475.64	

The total and annual potential e-waste generation at the University of Kwa-Zulu Natal are shown in table 5.4. the total e-waste generated at the University of Kwa-Zulu Natal is approximately 67,6 tons. The annual e-waste generated is approximately 13,5 tons.

Table 5.4: Summary of total e-waste generated at the University of Kwa-Zulu Natal

	Total	Annual contribution
Desktop (Kg)	53056	10 611.1
Printers/ Photocopier (Kg)	5796	1159.2
Air Conditioning units (Kg)	8165	1633
Projectors (Kg)	609	121.7
Total (Kg)	67626	13525.2

The University of Kwa-Zulu Natal has approximately 45 000 registered students (UKZN stats, 2016); therefore, approximately 0.3 kg/per person of e-waste is generated. There is a potential reason to believe that this figure could increase as the sample size collected at UKZN was limited. The limitation was that only selected e-waste was collected, and the e-waste was collected from specific areas. While the e-waste generated from UKZN is relatively low compared, it is still a significant volume in terms of economic value and environmental concern.

5.1.8 Research questionnaire: Section A (Responses to disposal)

The average responses from the five campuses are shown in figure 5.11. The data concluded that across all five campuses (See appendix D) the various responses to each question strongly correlated which each other (as shown in table 5.5).

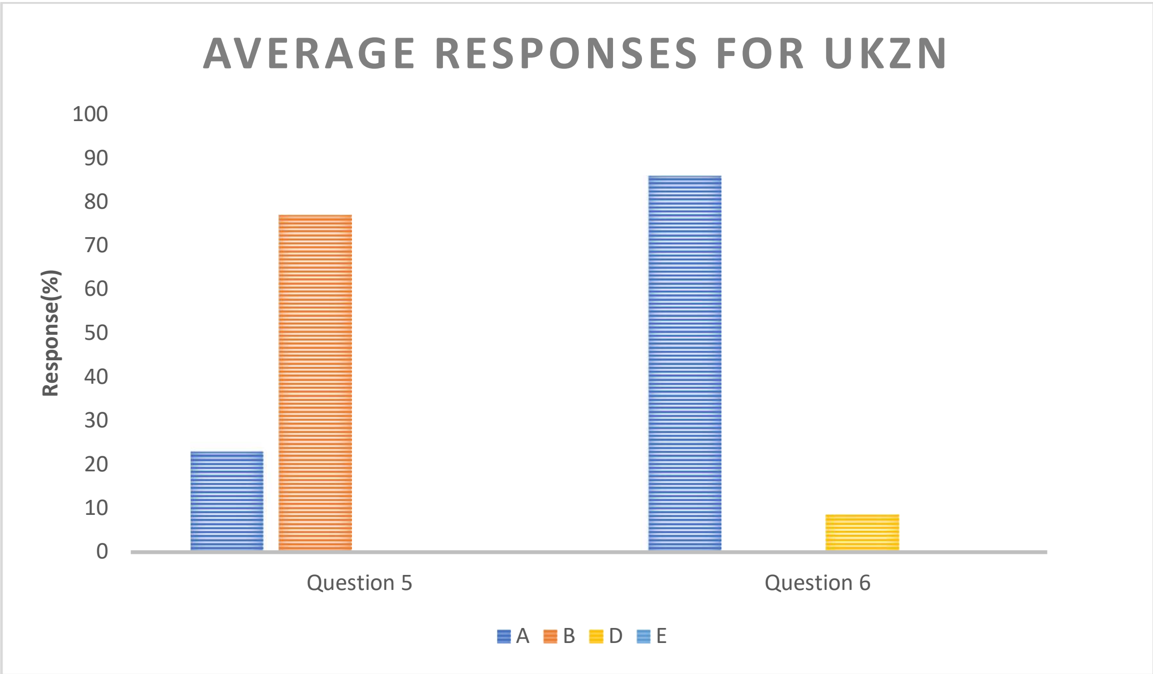


Figure 5.11: Average responses for section A

In Section A, Question 5 the majority (75%) of the respondents across all five campuses stated that the main reason for the disposal of electronics is obsolete hardware (as shown in table 5.5). The other significant response for electronic devices disposal is that the electronic devices were either broken or malfunctioning.

The above findings correlated with the study by Debnath, et al. (2016), in which the two major reasons for the disposal of electronic devices are planned obsolesce, (when electronic devices come to the end of their natural lifecycle). The second perceived obsolesce (whereby electronic devices seem redundant compared to new electronic devices that pose improved characteristics such as processing speed and design).

In the same study, the researcher concluded that the reason for the disposal of electronic devices leaned slightly towards perceived obsolesce over planned obsolesce but not by much. However, the researcher noted that due to the rapid innovation of electronic devices, electronic devices' disposal because of perceived obsolesce will increase.

In Section A, Question 6 the majority (85%) of the respondents across all five campuses stated that electronic devices' condition upon disposal was in excellent condition (84%). While a small fraction stated either moderate (4%) or in poor condition (9%) (as shown in table 5.5).

This finding strongly correlates with the research of Debnath, et al. (2016), as the electronic devices that are disposed at the University of Kwa-Zulu Natal is generally perceived obsolesce. A small fraction of respondents stated that the reason they dispose of electronic devices is that they were in poor quality either broken or malfunctioned. The electronic devices are damaged during normal use or by user negligence.

Table 5.5: Section A responses

Section A: Questions	**Most popular response**				
	Howard campus	Westville campus	Medical school campus	PMB campus	Edgewood campus
5. What is the main reason why electronic are disposed in your organisation?	**A (19%)** Broken or malfunctioning. **B (81%)** Obsolete hardware	**A (25%)** Broken or malfunctioning. **B (75%)** Obsolete hardware	**A (33.3%)** Broken or malfunctioning. **B (66.67%)** Obsolete hardware	**A (19%)** Broken or malfunctioning. **B (81%)** Obsolete hardware	**A (18%)** Broken or malfunctioning. **B (82%)** Obsolete hardware
6. What is the condition of the electronics in your organisation, upon disposal?	**A (79%)** Excellent **C (7%)** Moderate **D (14%)** Low quality	**A (87.5%)** Excellent **C (6.25%)** Moderate **D (6.25%)** Low quality	**A (100%)** Excellent	**A (81%)** Excellent **C (4.7%)** Moderate **D (14.3%)** Low quality	**A (82%)** Excellent **B (9%)** Moderate **D (9%)** Low quality

5.2. Research questionnaire: Section B

In this section, the current electronic waste management practises of the five campuses of the University of KwaZulu Natal were analysed. The current waste management plan of the organisation, the current disposal practices, the information regarding e-waste management and the importance of having an e-waste management plan were evaluated. The detailed methodology of how the data from the questionnaire (Section B) was analysed to obtain the necessary data is shown in appendix D. The average response of the five campuses are shown in figure 5.12.

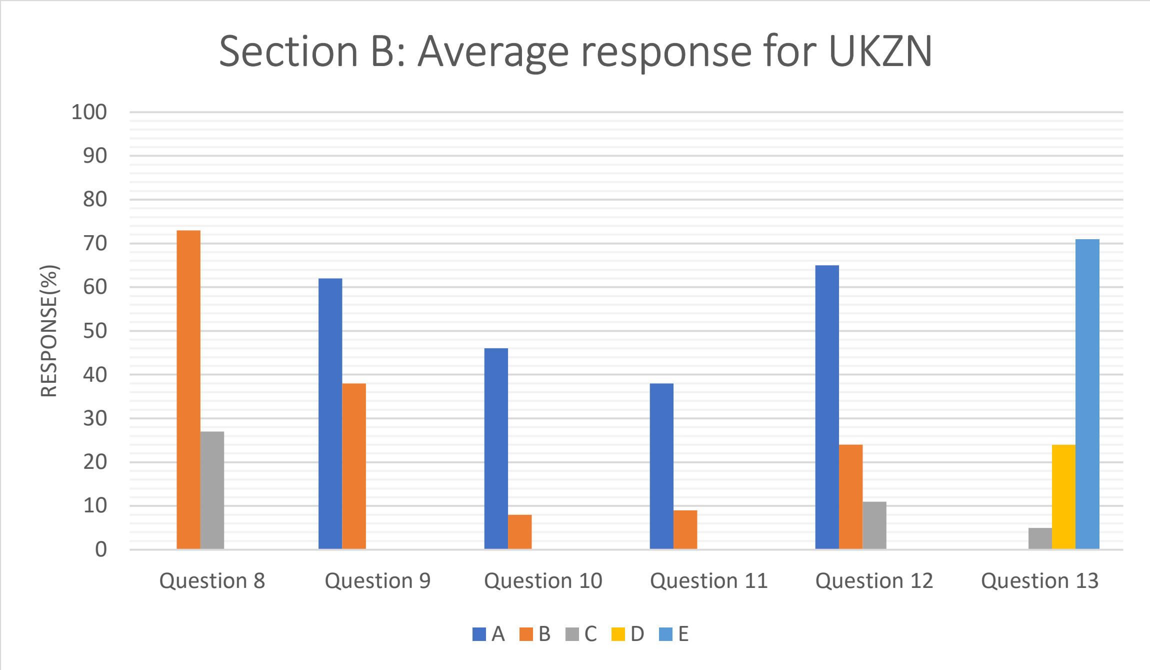


Figure 5.12: Average responses for Section B

In section B, question 8, the majority (73%) of respondents stated that their organisation doesn't have a specified waste management plan (as shown in table 5.6). While the remaining participants indicated that they were not sure.

According to Otsuka et al. (2012), there is no formalised electronic waste management plan in most of Africa (and much of the rest of the developing world). Each organisation/person has to independently choose how to dispose of obsolete and malfunctioning electronic devices. Therefore, the study's findings compare with previous studies that there is no formalised electronic waste management plan at this moment in time.

In section B, question 9, most (62%) declared that their organisation/facility stored obsolete and malfunctioning electronic devices (as shown in table 5.6). While a significant fraction (38%) stated that they disposed of obsolete and malfunctioning electronic devices.

In section B, question 10 the majority (31% of total available) of respondents stated that they stored their e-waste because they were not aware of any authorised e-waste agent to dispose of the e-waste (as shown in table 5.6).

This finding correlates with the finding that in KwaZulu natal as a whole, there are only 6 Authorised e-waste recyclers (five small scales and one medium) (Appendix B). According to Amuzu (2018), the e-waste recycling industry is still in its infancy in South Africa (and in most developing countries). Therefore, only a small fraction of e-waste is recycled each year (South Africa 10-12%).

In section B, question 11, 40.5 % of respondents stated they disposed of electronics, 31.5% of which treated e-waste as ordinary municipal waste and disposed of it in the trash, while 9.5% donated their obsolete and malfunctioning electronics (as shown in table 5.6).

The above findings show some correlations with a study by (Machete, 2017) in which significant volumes of e-waste were found in municipal landfill sites in Southern Africa. In the same study, the researcher concluded that the volumes of e-waste in landfill sites will increase as electronic consumption in Southern Africa grows.

In section B, question 12, the majority of the participants strongly disagreed 64%) and disagreed (31%) that there is sufficient information regarding e-waste management available (as shown in table 5.6).

The above finding correlates with the current e-waste management scenario, while there is no formalised e-waste management plan in South Africa or official municipal information available, there are many international and local organisations that are trying to provide information on sustainable e-waste management (Ledwaba & Sosibo, 2017).

In section B, Question 13 the majority of the respondents strongly agreed (72%) and agreed (24%) that it is essential to have an integrated waste management plan for e-waste (as shown in table 5.6). As of the time of writing, there is no formalised e-waste management strategy in South Africa; however, there are independent organisations nationally and internationally seeking to solve the problem (Zenegg et al., 2014).

The international organisations that have realised that better e-waste management practises are needed, such as the Solving the e-waste problem (Step) initiative (2012), the European union's directive WEEE (2012) and the Basel convention (2012) these organisations sets about creating guidelines for e-waste management that includes environmental and social considerations. The local organisations that are providing guidelines and solutions to the e-waste problem in South Africa are e-Wasa and the e-waste alliance; these organisations seek to establish an electronic waste management system that is sustainable and environmentally sound. The formal implementation of an integrated e-waste management plan is inevitable as the e-waste problem grows, and this is shown in the study by the growing public concern.

Table 5.6: Section B responses

Section B: Questions	**Most popular response**				
	Howard campus	Westville campus	Medical school campus	PMB campus	Edgewood campus
7. Does your organisation have a specified electronic waste management plan?	**B (76%)** No **C (24%)** Not sure	**B (75%)** No **C (25%)** Not sure	**B (66,6%)** No **C (33,3%)** Not sure	**B (74%)** No **C (26%)** Not sure	**B (73%)** No **C (27%)** Not sure
8. If no, how does your organisations manage electronic waste, either store or dispose of obsolete/redundant electronic waste?	**A (59.5%)** Stores **B (40.5%)** Dispose	**A (62.5%)** Stores **B (37.5%)** Dispose	**A (66.6%)** Stores **B (33.3%)** Dispose	**A (60.8%)** Stores **B (40.2%)** Dispose	**A (63.6%)** Stores **B (36.4%)** Dispose
9. If store, which of the following can be a reason for storing electronic waste?	**A (50 %)** We are not aware of any authorised agent that will recycle our e-waste **B (9.5 %)** We have not yet given it thought	**A (50 %)** We are not aware of any authorised agent that will recycle our e-waste **B (12.5 %)** We have not yet given it thought	**A (33.3 %)** We are not aware of any authorised agent that will recycle our e-waste	**A (52 %)** We are not aware of any authorised agent that will recycle our e-waste **B (8.8 %)** We have not yet given it thought	**A (45.45 %)** We are not aware of any authorised agent that will recycle our e-waste **B (9.0 %)** We have not yet given it thought
10. If dispose, how does your organisation dispose of its obsolete/redundant	**A (31%)** Treat it as ordinary office bin/municipal waste	**A (31.25%)** Treat it as ordinary office	**A (66.6%)** Treat it as ordinary office	**A (35%)** Treat it as ordinary office	**A (27.3%)** Treat it as ordinary office bin/municipal waste

electronic and electrical equipment?	**D (9.5%)** Donate old electronic and electrical equipment	bin/municipal waste **D (6.25%)** Donate old electronic and electrical equipment	bin/municipal waste	bin/municipal waste **D (7.2%)** Donate old electronic and electrical equipment	**D (18.1%)** Donate old electronic and electrical equipment
11. To what extent do you agree or disagree with the statement that "there is Sufficient information available on electronic waste management.	**A (64%)** Strongly disagree **B (31%)** Disagree **C (5%)** Neither disagree or agree	**A (62.5%)** Strongly disagree **B (31.25%)** Disagree **C (6.25%)** Neither disagree or agree	**A (66.6%)** Strongly disagree **B (33.3%)** Disagree	**A (65.2%)** Strongly disagree **B (30.5%)** Disagree **C (4.3%)** Neither disagree or agree	**A (64%)** Strongly disagree **B (27.2%)** Disagree **C (8.8%)** Neither disagree or agree
12. To what extent do you agree or disagree with the statement that "it is important for organisations to have a strategy for the management of obsolete/redundant electronic and electrical equipment"?	**C (4.7%)** Neither disagree or agree **D (30.9%)** Agree **E (64.4%)** Strongly agree	**C (6.25%)** Neither disagree or agree **D (31.25%)** Agree **E (62.5%)** Strongly agree	**E (100%)** Strongly agree	**C (4.4%)** Neither disagree or agree **D (30.4%)** Agree **E (65.2%)** Strongly agree	**C (9.1%)** Neither disagree or agree **D (27.2%)** Agree **E (63.7%)** Strongly agree

5.3. Research questionnaire: Section C

In this section, the Importance of sustainable e-waste management across the five campuses of The University of Kwa-Zulu Natal were analysed. The participant's awareness of legislations that regard e-waste management and environmentally safe practices were evaluated. The participant's awareness of the harmful nature of e-waste, the impact of e-waste on the environment and the value of e-waste were evaluated. The detailed methodology of how the data from the questionnaire (Section C) was analysed to obtain the necessary data is shown in appendix D.

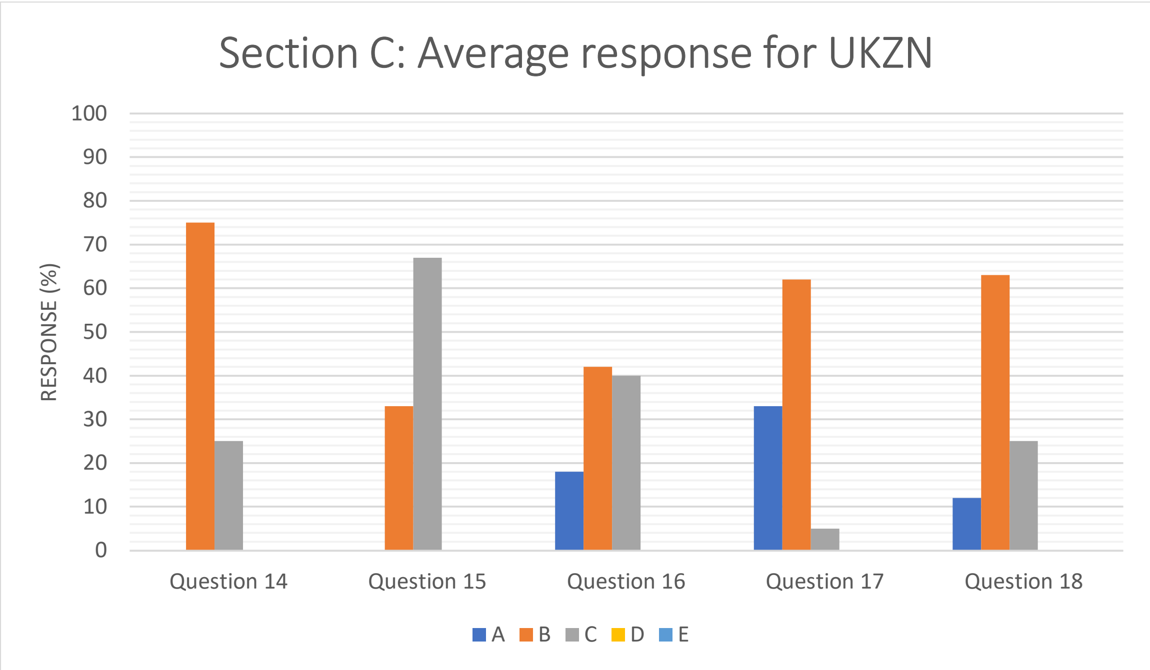


Figure 5.13: Average responses for section C

In section C, Question 13 the majority of participants (75%) were not aware of any legislation that deal with the disposal of obsolete/redundant electronic waste (as shown in table 5.7). The above finding is to be expected, as in South Africa there are no formal legislation (that are enforceable) to manage electronic waste, therefore participants should not be aware of any such laws.

In section C, Question 14 the participants either strongly disagreed (32%) or disagreed (68%) that there were aware of any environmental legislation regarding e-waste (as shown in table 5.7). While there are many waste management and environmental legislation protecting the environment from unsafe waste management practice, there are none in South Africa (as of yet) that is specific to e-waste.

In section C, Question 15 the participants strongly disagreed (18%) or disagreed (41%) that e-waste contains no harmful substance, and in question 16 the majority (62%) stated that they were aware of the health risks associated with e-waste (as shown in table 5.7).

According to Xavier, et al. (2019) electronic waste contains a significant amount of substances (Heavy metals) that can have adverse effects on human health and the environment. Electronic devices under normal use pose no threat, however upon disposal of e-waste these harmful substances can be released. E-waste if left undisturbed pose no significant problems, however many landfill sites have frequent heavy compaction (via track-type dozer), this activity easily breaks e-waste and allows the heavy metals to be released (Gutberlet & Uddin, 2017).

In section C, Question 17 the participants disagreed (61%) and strongly disagreed (12%) stated that they disagreed that e-waste contains no value (as shown in table 5.7). The above finding correlates well with the findings of the United Nations university (2018), that calculated that the average yearly volume of e-waste (44.7 million tons), is estimated to be worth 61 billion dollars. Most of the electronic waste is fully recyclable, and this waste stream highly lucrative.

Table 5.7: Section C responses

Section C: Questions	Most popular response				
	Howard campus	**Westville campus**	**Medical school campus**	**PMB campus**	**Edgewood campus**
13. Are you aware of any legislation that deals with the disposal of obsolete/redundant electronic and electrical equipment?	**B (90.5%)** No **C (9.5%)** Not sure	**B (93.75 %)** No **C (6.25 %)** Not sure	**B (66.7 %)** No **C (33.3 %)** Not sure	**B (60.9 %)** No **C (39.1 %)** Not sure	**B (66.7 %)** No **C (33.3 %)** Not sure
14. Are you aware of any environmental legislations regarding electronic waste?	**A (30.5%)** Strongly disagree **B (69%)** Disagree	**A (31.5%)** Strongly disagree **B (68.75%)** Disagree	**A (33.3%)** Strongly disagree **B (66.7%)** Disagree	**A (34.7 %)** Strongly disagree **B (52.2 %)** Disagree **C (13.1%)** Neither	**A (36.3%)** Strongly disagree **B (45.5%)** Disagree **C (18.2%)** Neither
15. To what extent do you agree or disagree with the statement that "obsolete/redundant electronic and electrical equipment contains no harmful substances to the environment"?	**A (14.3%)** Strongly disagree **B (35.7%)** Disagree **C (50%)** Neither	**A (12.5%)** Strongly disagree **B (37.5%)** Disagree **C (50%)** Neither	**A (33.3%)** Strongly disagree **B (66.6%)** Disagree	**A (13%)** Strongly disagree **B (34.8%)** Disagree **C (52.2%)** Neither	**A (18.1%)** Strongly disagree **B (36.3%)** Disagree **C (45.5%)** Neither
16. Are you aware of the health risks associated with electronic waste?	**A (50%)** Yes **B (37.5%)** No **C (14.3%)** Not sure	**A (50%)** Yes **B (37.5%)** No **C (12.5%)** Not sure	**A (66.6 %)** Yes **B (33.3 %)** No	**A (69.6%)** Yes **B (30.4%)** No	**A (72.7%)** Yes **B (27.3%)** No
17. To what extent do you agree or disagree with the statement that "obsolete/redundant electronic and electrical equipment contains no value"?	**B (59.5%)** Disagree **C (40.5%)** Neither	**B (62.5%)** Disagree **C (37.5%)** Neither	**B (66.6%)** Disagree **C (33.4%)** Neither	**A (34.4%)** Strongly disagree **B (60.9%)** Disagree **C (4.7 %)** Neither	**A (27.3%)** Strongly disagree **B (63.6%)** Disagree **C (9.1%)** Neither

5.4. Integrated waste management criteria

The study's findings will be used to set up an integrated waste management plan (IWMP) for electronic waste at the University of Kwa-Zulu Natal. The main criteria that will shape the bulk of the IWMP are the expected volumes, waste stream composition and quality of e-waste. The secondary criteria that must also be considered are the impact e-waste has on the environment and human health. The justification of an e-waste management plan will be discussed by analysing the demand and awareness of a sustainable e-waste management plan.

The Kwa-Zulu Natal University (UKZN) university generates a significant volume of e-waste approximately 13,52 tons a year (67,7 tons in a five-year period). The majority of e-waste (78.5 %) is desktop computers. The typical reason for the disposal of electronic devices at UKZN is that the hardware is obsolete. Most of the e-waste disposed at UKZN is in excellent condition.

The integrated waste management plan (IWMP) must consider the current waste management practice and seek to improve upon them to manage e-waste in an economical and environmentally sustainable manner.

The majority of the e-waste (70%) is currently being stored while the remainder (30%) is disposed into the municipal waste stream. However, while storage is a safe practice, it is not sustainable as the storage space is infinitely abundant and will eventually reach its capacity. Upon reaching storage limits, the e-waste stream will be diverted into the Municipal waste stream and be disposed into landfills. Therefore, 30% of waste disposed into MSW will likely increase soon.

The main rationale for the storage of e-waste is that the majority (50%) of respondents did not know how to safely dispose of e-waste and were in strong favour of creating an e-waste centred IWMP.

The environmental and legislative criteria that must be taken into consideration when designing the IWMP are:

- E-waste contains many harmful substances that can have adverse impacts on human health and the environment if not managed properly.

- There is currently no active and enforceable legislation specified around e-waste management; therefore, provisions must be made.

5.5 Conclusion

The University of Kwa-Zulu Natal generates a significant volume of e-waste, that must be managed in a safe and sustainable manner. The IWMP must take into consideration the economic and environmental impacts of e-waste. In the following chapter, the W.R.O.S.E model will be used to create the IWMP, the W.R.O.S.E model will take into consideration all the necessary factors.

Chapter 6: The Integrated waste management plan for the University of Kwa-Zulu Natal

6.1 Introduction

The IWMP for the University of Kwa-Zulu Natal will be created from the best strategies available. Due to the global pandemic's constraints (Covid-19) and time constraints, the IWMP will only be created for Howard and Westville campuses.

The waste stream and responses from questionnaires (Chapter 5) are remarkably similar for all five campuses. Therefore, the IWMP for Howard and Westville campuses can be used as a guide for the other campuses.

The criteria for selecting the best scenario are landfill space-saving, economic sustainability, environmental sustainability, institutional sustainability, and social sustainability. For the IWMP the total waste generated will be used for the calculations (i.e., Stored + disposed of e-waste). The proposed IWMP will be designed to accommodate both present and future e-waste generation.

6.2 UKZN Howard campus

There are four main scenarios used in this study (as shown in chapter 3.16). The scenarios will be evaluated based on the data obtained in the research questionnaire for Howard (Chapter 5), and the best option(s) will be selected for the IWMP. The data from chapter 5 is analysed (as shown in appendix E) to assess the sustainability indicators to select the best scenario(s) to create an IWMP for the Howard campus.

6.2.1. Scenario 1: Unsorted e-waste in the combined waste stream is collected by a contractor and is to be directly disposed in a landfill.

Scenario 1, figure 6.1, represents the status quo of waste disposal (Including e-waste), in South Africa. In scenario 1, the e-waste at UKZN is mixed in with the regular waste stream and is collected by a contractor. UKZN pay the contractor for the waste collection. The contractor disposes of the waste into a landfill site. Scenario 1 (The status quo) provides a baseline to compare the efficiency of the other scenarios. In scenario 1, UKZN is responsible for the waste up until the e-waste is collected from the contractor. The contractor is responsible for the e-waste until its final disposal into the landfill.

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL
W.R.O.S.E Scenario 1

Waste material or waste fraction	Landfill Disposal (Kg)	Landfill recovery (Kg)	Recycling (Kg)	Reuse/Resale (Kg)
PC	4606.65			
Printers	828			
Projectors	16.56			
Air conditioners	704.6			
Sum total	6155.81			
			Total	6155.81

Figure 6.1: Scenario 1 (Landfilling)

Howard campus generates over 6 tons of e-waste every year, (assume 1 m^3 = 1 ton) is 6,2 m^3 of landfill space being consumed every year. The largest contributing waste fraction of e-waste is desktop computers as it takes up 4.6 m^3.

Economic sustainability

In scenario 1, there is no revenue generated, and hence it has a negative net value (as shown in table 6.1). UKZN employs a private contractor (as shown in figure 6.1) to collect the solid waste from the Howard campus, in exchange for a service fee. Therefore, the cost of landfilling e-waste is much higher than the estimate in table 6.1. Scenario 1 is not financially sustainable, and the cost incurred will increase in future. In scenario 1, since the volume of waste disposal is relatively low, there is also a low potential to create jobs.

Table 6.1: Howard campus: scenario 1 (economic analysis)

W.R.O.S.E Scenario 1 (Economic analysis)					
Strategy	Tons/year	Cost	Revenue	Net	Job creation potential
Landfill Disposal	6.16	R 4,428.12	-	R -4,428.12	1
Landfill recovery					
Recycling					
Reuse/Resale					
Total	6.16	R 4,428.12	R 0.00	R -4,428.12	1

Environmental sustainability

In scenario 1, there is a potential to generate a significant amount of greenhouse gases (see table 6.2). The greenhouse gases generated in scenario 1 originates primarily from the transportation of the waste (The detailed calculation can be seen in appendix E9). In scenario 1, a significant amount of heavy metals enter the landfill site (as shown in table 6.2). According to Xavier et al. (2019), e-waste landfilling can have severe consequences on the environment. The heavy metals in e-waste when released create toxic leachate, that affects the balance of the landfill (methane production) and adversely affects the fauna and flora in the nearby area (Xavier. et al., 2019).

Table 6.2: Howard campus: scenario 1 (environmental analysis)

W.R.O.S.E Scenario 1 (Emissions analysis)					
Strategy	Carbon emissions (Kg)		Toxic emissions(Kg)		
	C02	CH3	Cadmium	Copper	Lead
Landfill Disposal	309.36		14.04	162.48	5.55
Landfill recovery					
Recycling					
Reuse/Resale					
Total	309.36	0.00	14.04	162.48	5.55

Social sustaianbilty

Scenario 1, requires little public participation as waste generators (UKZN) have to just place the waste at a central collection point, where it is to collect.

E-waste if left undisturbed poses no significant problems, however many landfill sites have frequent heavy compaction (via track-type dozer), this activity easily breaks e-waste and allows the heavy metals to be released (Gutberlet & Uddin, 2017).

In reference to chapter 2.12.3, e-waste is often targeted by waste pickers for valuable metals and components (Gutberlet & Uddin 2017). According to Langa (2019), the waste pickers primarily target garbage refuse bags (usually at the source of waste generation). However, waste at UKZN is often stored in a secure area (inside campus property) there is a low potential of access to waste pickers (Langa, 2019).

Therefore, the e-waste from UKZN will be targeted by the waste pickers at the landfill sites (Gutberlet & Uddin, 2017). According to Neto, et al. (2019) e-waste pickers often are not technically trained to dismantle e-waste and often just break off the value materials, this improper processing of e-waste can release many of the toxic substances in the e-waste (see chapter 2.12).

Institutional sustainability

With reference to chapter 2.14, there are several key legislations put into place to ensure safe and sustainable waste management in South Africa. The legislations were established to enforce the correct management and disposal of waste:

- The National Environmental Management Act No. 107 of 1998 (NEMA).
- The Environment Conservation Act No. 73 of 1989 (ECA).
- The White Paper on Integrated Pollution and Waste Management (2000).
- The National Waste Management Strategy (NWMS 2008).

However, the above legislation only accounts for general and inert waste and e-waste (as contains several toxic materials, see chapter 2.6) cannot be disposed of in accordance with the above. At present, there is no specific (enforceable) legislation in South Africa that is centred around the sustainable management and disposal of e-waste.

In chapter 5.2, the majority of participants agreed that there was a need for an e-waste management strategy and that it was important to have a sustainable e-waste management plan. According to chapter 5.3, The main reason why the participants of the study agreed to the creation of an IWMP is that there were aware of the toxic material found in e-waste and the impact it had on human health and the environment. The findings of chapter 5, indicate that there is demand for the creation of an IWMP and legislations for the sustainable management and safe disposal of e-waste in UKZN.

6.2.2 Scenario 2: Unsorted e-waste in the combined waste stream is collected by a contractor, the contractor separates e-waste from the stream and sells it to a recycling agent.

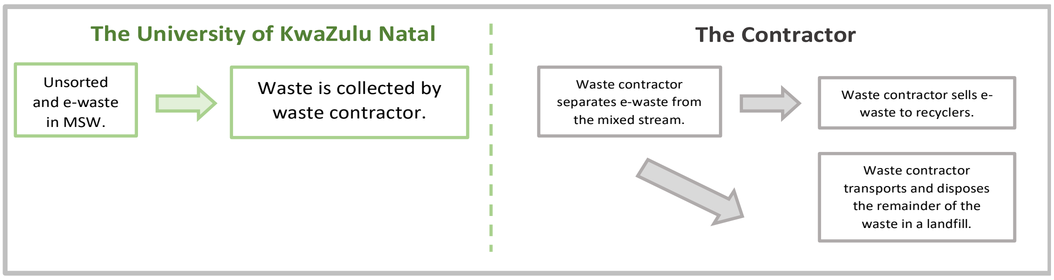
In scenario 2, as shown in figure 6.2, unsorted e-waste is collected by a contractor. UKZN pay for the waste collection. The contractor separates e-waste from the waste stream and sells it to a recycling agent. The remainder of the waste is to be disposed into a landfill site. In scenario 2, a substantial amount of the e-waste is diverted from landfills.

In a study by Andarani & Goto (2012) the typical e-waste recycling facility can produce between 5-10 % of residual waste. In this study 10% residual waste is assumed. Therefore 10% of the total e-waste will be disposed into a landfill.

In scenario 2, the e-waste is mixed in with the waste stream, therefore a material recovery operation must be undertaken by the contractor. The e-waste generated by UKZN is typically large items (see chapter 5), therefore the e-waste can easily be removed by hand. Therefore there is no need to create a material recovery facility to separate the e-waste.

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL

W.R.O.S.E Scenario 2



Waste material or waste fraction	Landfill Disposal (Kg)	Landfill recovery (Kg)	Recycling (Kg)	Reuse/Resale (Kg)
PC	460.665		4145.985	
Printers	82.8		745.2	
Projectors	1.656		14.904	
Air conditioners	70.46		634.14	
Sum total	615.581		5540.229	
			Total	6155.81

Figure 6.2: Howard campus (scenario 2)

Economic sustainability

Scenario 2 has the potential to be economically sustainable and potentially profitable for the contractor. In scenario 2, the main cost for the contractor is the transportation and separation of the e-waste from the mixed stream. The contractor has two main sources of revenue from this scenario, the first is the collection charge received from UKZN and the second is from the sale of the e-waste to the recycler.

E-waste recycling, as shown in table 6.3, has a significant profit margin, approximately 90% profit margin. Therefore, the initial cost of separating the e-waste from the mixed stream may be lucrative as the contractor can sell the e-waste at a premium. In scenario 2, the contractor has the potential to create 4 permanent jobs (as shown in table 6.5).

Table 6.3: Howard campus: scenario 2 (economic analysis)

W.R.O.S.E Scenario 2 (Economic analysis)					
Strategy	Tons/year	Cost	Revenue	Net	Job creation potential
Landfill Disposal	0.62	R 442.81	R 0.00	R -422.81	1
Landfill recovery					
MRF					
Recycling	5.54	R 13,708.17	R150,122.64	R136,414.47	3
Reuse/Resale					
Total	6.16	R 13,708.17	R 150,122.64	R 136,414.47	4

Environmental sustainability

In scenario 2, the majority of e-waste is diverted from landfill's sites. The recycling of e-waste does produce some waste (see chapter 2.11), most of this is from the unrecyclable plastics and the toxic materials (such as cadmium and lead) found in the components (see chapter 2.12). The toxic material is made the first inert by using stabilization agents and then disposed of. The above ensures that e-waste will not endanger the health of humans and the environment.

There are two sources of greenhouse gas emission in scenario 2, the first is the transportation of e-waste and the second is the recycling of e-waste. Most of the gas emissions originate from the transportation of the e-waste (see appendix E). Table 6.4 show the summary of the total gas emissions from scenario 2.

The most common method of e-waste recycling, in KwaZulu natal where the study is based, is pyrolysis (see chapter 3.19.3). While there are some gas emissions from pyrolysis, this volume is significantly less than producing virgin materials (see chapter 2.10.3). The recycling of e-waste reduces the consumption of virgin material, as the recycled, materials re-enter the manufacturing cycle to meet consumer demand.

Table 6.4: Howard campus: scenario 2 (environmental analysis)

W.R.O.S.E Scenario 2 (Emissions analysis)					
Strategy	Carbon emissions (Kg)		Toxic emissions (Kg)		
	C02	CH3	Cadmium	Copper	Lead
Landfill Disposal	30.94		1.40	16.25	3.61
Landfill recovery					
Recycling	268,019.25	321,623.10	14.04	162.48	5.55
Reuse/Resale					
Total	268,019.3	321623.1	15.44	178.72	9.16

Social sustainability

In scenario 2, the waste Is collected by the contractor; therefore, no source separation is required by UKZN staff, the waste has to just be placed at the relative collection points. The relative simplicity of this scenario (for UKZN) will aid the long term sustainability of this scenario. The recycling of e-waste will ensure the toxic material found in e-waste will affect human health and the environment.

Institutional sustainability

There is no specific legislation regarding e-waste management in South Africa. With reference to chapter 2.14.1, there are several guidelines on safe and sustainable e-waste management. The most well know of these guides are:

- The Basel convention (2011)
- The European union's WEEE directive (2012/19/EU)
- Solving the e-waste problem (STEP) (2012)

However, these guidelines are based on the global e-waste problem and not specified in the South African context. The above guidelines are targeted around consumer e-waste and stopping the transboundary movement (see chapter 2.4.2) of e-waste, these guidelines will not be effective in the case of an educational facility such as UKZN.

There are South African based organisations such as eWASA that focus on e-waste management in a South African context (see chapter 2.14.3) however these guidelines focus

on consumer e-waste and will not be effective in the case of an educational facility such as UKZN.

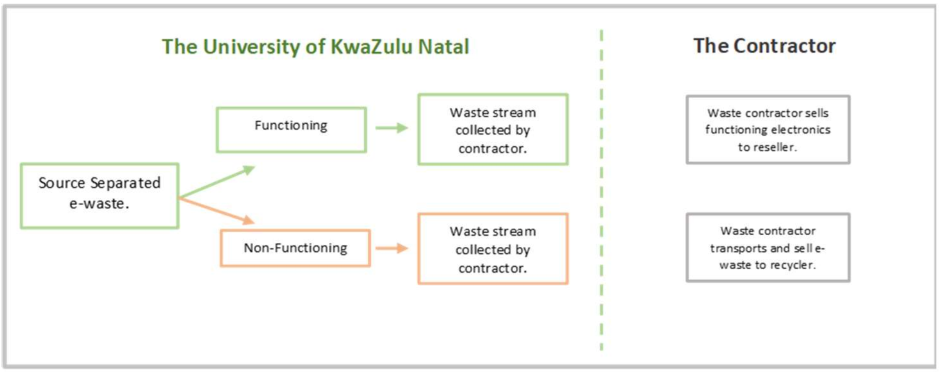
Therefore, there is a need for an e-waste management plan for an educational institute such as UKZN. The findings of chapter 5, provide support for the above and the need for the creation of an IWMP and legislations for the sustainable management and safe disposal of e-waste in UKZN.

6.2.3 Scenario 3: Source separated e-waste, is sold to the contractor. The contractor refurbishes the functioning electronics and sells to resale agent. The contractor sells the non-functioning electronics to a recycler.

In scenario 3, as shown in figure 3.5, a holistic, integrated waste management solution is adopted. The e-waste is to be separated at the source and be divided based on functionality. The e-waste is to be source-separated at UKZN and then sold to the contractors. According to chapter 5, 10 % of electronics are in poor condition and are to be landfilled, 10% are in moderate condition and are to be recycled and 80% are in excellent condition and are to be refurbished and reused.

The contractors are to refurbish the functioning electronics and sell them to a resale agent. The electronics that are functioning are to be refurbished and reused, as a large part of South Africa does not have access to technology, and they will benefit from access to more affordable electronics. The non-functioning e-waste will be sold by the contractor to a recycling agent. Most recyclers in South Africa do not have the capacity to recycle metals and plastics, therefore the recyclables are only extracted by recyclers and sold to smelters and to remanufacturers (see chapter 2.14).

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL
W.R.O.S.E Scenario 3



Waste material or waste fraction	Landfill Disposal (Kg)	Landfill recovery (Kg)	Recycling (Kg)	Reuse/Resale (Kg)
PC	460.7		460.7	3685.3
Printers	82.8		82.8	662.4
Projectors	1.7		1.7	13.2
Air conditioners	70.5		70.5	563.7
Sum total	615.6		615.6	4924.6
			Total	6155.81

Figure 6.3: Howard campus (Scenario 3)

In scenario 3, approximately 90% of e-waste is diverted from landfill. The majority of the 10% being disposed into landfills is from the desktops (Mainly the plastic monitor case) printers and units, mainly the plastic fraction as it is not economical to recycle.

Economic sustainability

In scenario 3, most of the electronics that are to be reused/resold, are in excellent condition and little maintenance and repair work is required; therefore, there is a great potential to generate revenue from this scenario (as shown in table 6.5).

According to the e-waste recyclers (See appendix E), there is no collection charge for e-waste; there is no compensation in return. The revenue generated from e-waste recycling is used to cover all the costs and overheads. However, as shown in table 6.7, there is a large profit margin, approximately 90% profit margin for the e-waste recycler, and therefore, e-waste recycling is an economically sustainable option. In scenario 3, there is potential to create an additional 7 permanent jobs (as shown in table 6.7), most of which are from the resale of electronics.

Table 6.5: Howard campus: scenario 3 (economic analysis)

W.R.O.S.E Scenario 3 (Economic analysis)					
Strategy	Tons/year	Cost	Revenue	Net	Job creation potential
Landfill Disposal	0.62	R 442.81	R 0.00	R -422.81	1
Landfill recovery					
Recycling	0.62	R 1,370.82	R 12,193.57	R 10,822.76	1
Reuse/Resale	4.92	R 0.00	R 1,829,680.00	R 1,829,680.00	5
Total	6.16	R 1,813.63	R 1,841,873.57	R 1,840,079.94	7

Environmental sustainability

In scenario 3, most e-waste from UKZN is diverted from landfill sites (90%); therefore, there is a substantial decrease in the amount of toxic material entering landfill sites from UKZN.

There are two sources of greenhouse gas emission in scenario 3, the first is the transportation of e-waste and the second is the recycling of e-waste (see appendix E9 for detailed calculations). Most of the gas emission in scenario 3 originate from the transportation of the e-waste (see Appendix E9). Table 6.6 shows a summary of the total gas emissions from scenario 3.

For the purpose of this study, pyrolysis is assumed to be used for all e-waste recycling, as pyrolysis is the most common method of e-waste recycling in KwaZulu Natal (see table 3.19).

While there are some gas emissions from pyrolysis, this volume is significantly less than producing virgin materials (see chapter 2.10.3). In addition, recycling of e-waste, prevents the consumption of virgin material, as the recycled, materials re-enter the manufacturing cycle (see chapter 2.8).

The waste material is made first inert by using stabilization agents and then disposed of (see chapter 2.10). The reuse/resale of electronics prevents the consumption of virgin material to manufacture new electronics, therefore mitigating the harmful emissions during production (see chapter 2.10.3). The above ensures that e-waste will not endanger the heath of human health and the environment.

Table 6.6: Howard campus: scenario 3 (environmental analysis)

W.R.O.S.E Scenario 3 (Emissions analysis)					
Strategy	Carbon emissions (Kg)		Toxic emissions (Kg)		
	C02	CH3	Cadmium	Copper	Lead
Landfill Disposal	30.94		1.40	16.25	3.61
Landfill recovery					
Recycling	26801.93	32162.31	11.23	129.98	0.55
Reuse/Resale					
Total	26832.86	32162.31	12.63	146.23	4.17

Social sustainability

In scenario 3, the e-waste is required to be sorted at the source by the waste generator. However, at the University of KwaZulu Natal, the e-waste is stored separately from the regular waste; therefore, there will be no additional labour required. UKZN will leave all separated e-waste at collection points, for the contractor to collect.

The reuse and recycling of the e-waste will substantially reduce the amount of toxic material in e-waste being disposed of by UKZN into landfill sites. The reduction in e-waste being disposed of will benefit human health (in particular the waste pickers at the landfill site) and the environment (landfill sites in particular).

Institutional sustainability

There is no specific legislation regarding e-waste management in South Africa. With reference to chapter 2.14.1, there are several guidelines on safe and sustainable e-waste management. The most well know of these guides are:

- The Basel convention (2011)
- The European union's WEEE directive (2012/19/EU)
- Solving the e-waste problem (STEP) (2012)

However, these guidelines are based on the global e-waste problem and not specified in the South African context. The above guidelines are targeted around consumer e-waste and stopping the transboundary movement (see chapter 2.4.2) of e-waste, these guidelines will not be effective in the case of an educational facility such as UKZN.

There are South African based organisations such as eWASA that focus on e-waste management in a South African context (see chapter 2.14.3) however these guidelines focus on consumer e-waste and will not be effective in the case of an educational facilities such as UKZN.

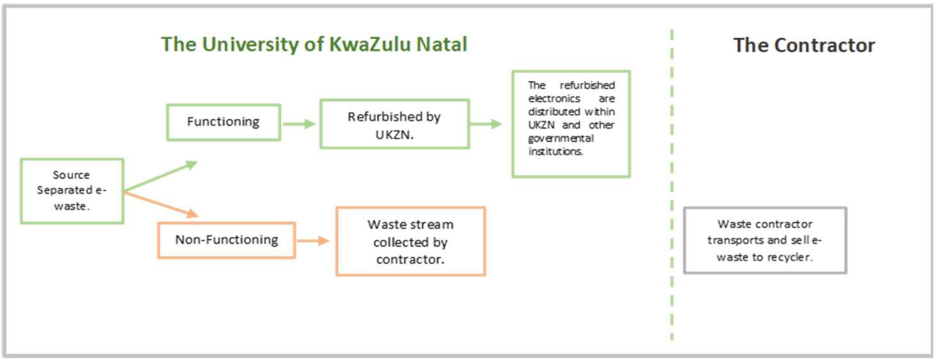
Therefore, there is a need for an e-waste management plan for an educational institute such as UKZN. The findings of chapter 5, provide support for the above and the need for the creation of an IWMP and legislations for the sustainable management and safe disposal of e-waste in UKZN.

6.2.4. Source separated e-waste. The functioning e-waste to be refurbished by UKZN and be reused internally or by another government agent. The non-functioning e-waste is to be sold by the contractor to a recycling agent.

In scenario 4 (as shown in figure 6.4), a holistic, integrated waste management solution is adopted. The e-waste is to be separated at the source and be divided based on functionality. The e-waste is to be source-separated at UKZN, and the non-functioning fraction is sold to the contractors. According to chapter 5, 10 % of electronics are in poor condition and are to be landfilled (made inert before disposal), 10% are in moderate condition and are to be recycled and 80% are in excellent condition and are to be refurbished and reused.

The non-functioning e-waste will be sold by the contractor to a recycling agent. Most recyclers in South Africa do not have the capacity to recycle metals and plastics, therefore the recyclables are only extracted by recyclers and sold to smelters and to remanufacturers (see chapter 2.14). The functioning electronics are to be refurbished, the functioning electronics are to be reused internally by UKZN or by another government agent. The electronics that are functioning are to be refurbished and reused, as a large part of South Africa does not have access to technology, and they will benefit from access to more affordable electronics.

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL
W.R.O.S.E Scenario 4



Waste material or waste fraction	Landfill Disposal (Kg)	Landfill recovery (Kg)	Recycling (Kg)	Reuse/Resale (Kg)
PC	460.665		460.665	3685.32
Printers	82.8		82.8	662.4
Projectors	1.656		1.656	13.248
Air conditioners	70.46		70.46	563.68
Sum total	615.581		615.581	4924.648
			Total	6155.81

Figure 6.4: Howard campus (scenario 4)

In scenario 4, approximately 90% of e-waste is diverted from landfill. The majority of the 10% being disposed into landfills is residual waste from recycling operations.

Economic sustainability

In scenario 4, most electronics that are to be reused/resold, are in excellent condition and little maintenance and repair work is required; therefore, there is a great potential to generate revenue from this scenario (as shown in table 6.7).

According to the e-waste recyclers (See appendix E), there is no collection charge for e-waste; there is no compensation in return. The revenue generated from e-waste recycling is used to cover all the costs and overheads. However, as shown in table 6.7, there is a large profit margin, approximately 90% profit margin for the e-waste recycler, and therefore, e-waste recycling is an economically sustainable option.

In scenario 4, there is potential to create additional 7 permanent jobs (as shown in table 6.9), most of which are from the resale of electronics.

Table 6.7: Howard campus: scenario 4 (economic analysis)

W.R.O.S.E Scenario 4 (Economic analysis)					
Strategy	Tons/year	Cost	Revenue	Net	Job creation potential
Landfill Disposal	0.62	R 442.81	R 0.00	R -422.81	1
Landfill recovery					
Recycling	0.62	R 1,370.82	R 12,193.57	R 10,822.76	1
Reuse/Resale	4.92	R 0.00	R 1,829,680.00	R 1,829,680.00	5
Total	6.16	R 1,813.63	R 1,841,873.57	R 1,840,079.94	7

Environmental sustainability

In scenario 4, most e-waste from UKZN is diverted from landfill sites (90%); therefore, there is a substantial decrease in the amount of toxic material entering landfill sites from UKZN. There are two sources of greenhouse gas emission in scenario 3, the first is the transportation of e-waste and the second is the recycling of e-waste (see appendix E9 for detailed calculations). Most of the gas emissions in scenario 4 originate from the transportation of the e-waste (see Appendix E9). Table 6.8 shows a summary of the total gas emissions from scenario 4.

For the purpose of this study, pyrolysis is assumed to be used for all e-waste recycling, as pyrolysis is the most common method of e-waste recycling in KwaZulu Natal (see table 3.19). While there are some gas emissions from pyrolysis, this volume is significantly less than producing virgin materials (see chapter 2.10.3). In addition, recycling of e-waste, prevents the consumption of virgin material, as the recycled, materials re-enter the manufacturing cycle (see chapter 2.8).

The waste material is made the first inert by using stabilization agents and then disposed of (see chapter 2.10). The reuse/resale of electronics prevents the consumption of virgin material to manufacture new electronics, therefore mitigating the harmful emissions during production (see chapter 2.10.3). The above ensures that e-waste will not endanger the health of humans and the environment.

Table 6.8: Howard campus: scenario 5 (environmental analysis)

W.R.O.S.E Scenario 3 (Emissions analysis)					
Strategy	Carbon emissions (Kg)		Toxic emissions (Kg)		
	C02	CH3	Cadmium	Copper	Lead
Landfill Disposal	30.94		1.40	16.25	3.61
Landfill recovery					
Recycling	26801.93	32162.31	11.23	129.98	0.55
Reuse/Resale					
Total	26832.86	32162.31	12.63	146.23	4.17

Social sustainability

In scenario 4, the e-waste is required to be sorted at the source by the waste generator. However, at the University of KwaZulu Natal, the e-waste is stored separately from the regular waste; therefore, there will be no additional labour required. UKZN will leave all separated e-waste at collection points, for the contractor to collect.

The reuse and recycling of the e-waste will substantially reduce the amount of toxic material in e-waste being disposed of by UKZN into landfill sites. The reduction in e-waste being disposed of will benefit human health (in particular the waste pickers at the landfill site) and the environment (landfill sites in particular).

Institutional sustainability

There is no specific legislation regarding e-waste management in South Africa. With reference to chapter 2.14.1, there are several guidelines on safe and sustainable e-waste management. The most well know of these guides are:

- The Basel convention (2011)
- The European union’s WEEE directive (2012/19/EU)
- Solving the e-waste problem (STEP) (2012)

However, these guidelines are based on the global e-waste problem and are not specified in the South African context. The above guidelines are targeted around consumer e-waste and stopping the transboundary movement (see chapter 2.4.2) of e-waste, these guidelines will not be effective in the case of an educational facility such as UKZN.

There are South African based organisations such as eWASA that focus on e-waste management in a South African context (see chapter 2.14.3) however these guidelines focus

on consumer e-waste and will not be effective in the case of an educational facility such as UKZN.

Therefore, there is a need for an e-waste management plan for an educational institute such as UKZN. The findings of chapter 5, provide support for the above and the need for the creation of an IWMP and legislations for the sustainable management and safe disposal of e-waste in UKZN.

6.2.5 Selection of IWMP strategy for UKZN Howard

The design of IWMP must consider the economic feasibility and the sustainability of the strategy for both the short and the long term.

The best scenario in the short term is to implement scenario 3. In scenario 3, the functioning fraction (80% of the waste stream) of the e-waste will be refurbished and resold, and the non-functioning fraction will be recycled (20% of the waste stream). UKZN sell the e-waste to contractors who are then responsible for the management and disposal of the e-waste. This scenario is lucrative for the contractor as there are high potential revenues.

Scenario 3 is preferred over scenario 4, as in this scenario UKZN has no responsibility in the management of the e-waste after the e-waste has been handed over to the contractor. In terms of a practicality perspective, it will be easier for UKZN to implement scenario 3 over scenario 4 as there is less investment required, in both financial and institutional means. According to Marshall & Stephenson (2020) in South Africa, only 30% of the population has access to any computer equipment (i.e., Desktop, Printers and projectors). Therefore, the refurbished electronics (which cost approximately 40-50% of new electronics) will allow many more people access to computer equipment. The e-waste recycling industry in South Africa is relatively new, and still in its infancy (only small and medium-sized facilities), therefore may not have the capacity to recycle large volumes of e-waste (see chapter 3).

In the short term, scenario 4 is both economically feasible and sustainable. In scenario 4, 90% of e-waste is diverted from landfills; this saves landfill space and prevents toxic material from entering the landfill. The potential revenue generated from this scenario offsets the cost and creates an additional 7 permanent jobs.

The best long-term solution will be scenario 2, as in the future the demand for preowned electronics will drastically decrease. The driving forces behind this rapid decrease in demand for electronics are the increased buying power of consumers (consumers having more disposable income, chapter 2.6), and sector-based growth (electronic devices becoming more economical, see chapter 2.5.2). The above factor will influence South Africa significantly as South Africa is a developing country and is expected to grow much in the future (Chapter 2.4.3).

Hence, as the demand for pre-owned electronics will decrease; therefore, the most feasible solution in the long term will be to recycle the entire e-waste stream. In the long term, optimistically the e-waste recycling industry will grow and will be able to recycle large volumes of e-waste.

The use of the above scenarios for the IWMP of Howard campus will ensure sustainable e-waste management in the short term and long term.

6.3. Westville campus

There are four main scenarios used in this study (as shown in chapter 3.16). The scenarios will be evaluated based on the data obtained in the research questionnaire for Westville (Chapter 5), and the best option(s) will be selected for the IWMP. The data from chapter 5 is analysed (as shown in appendix E) to assess the sustainability indicators to select the best scenario(s) to create an IWMP for the Westville campus.

6.3.1. Westville campus scenario 1: Unsorted e-waste in the combined waste stream is collected by a contractor and is to be directly disposed in a landfill.

Scenario 1, figure 6.5, represents the status quo of waste disposal (Including e-waste), in South Africa. In scenario 1, the e-waste at UKZN is mixed in with the regular waste stream and is collected by a contractor. UKZN pay the contractor for the waste collection. The contractor disposes of the waste into a landfill site. Scenario 1 (The status quo) provides a baseline to compare the efficiency of the other scenarios. In scenario 1, UKZN is responsible for the waste up until the e-waste is collected from the contractor. The contractor is responsible for the e-waste until final disposal into the landfill.

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL

W.R.O.S.E Scenario 1

Waste material or waste fraction	Landfill Disposal (Kg)	Landfill recovery (Kg)	Recycling (Kg)	Reuse/Resale (Kg)
PC	2386.7			
Printers	138			
Projectors	6.48			
Air conditioners	286			
Sum total	2,817.18			
			Total	2,817.18

Figure 6.5: Westville campus Scenario 1 (Landfilling)

Westville campus generates over 2,8 tons of e-waste every year, that is 2,8 m^3 of landfill space being consumed every year. The largest contributing waste fraction of e-waste is desktop computers as it takes up 2,3 m^3.

Economic sustainability

In scenario 1, there is no revenue generated, and hence it has a negative net value (as shown in table 6.9). UKZN employs a private contractor (as shown in figure 6.5) to collect the solid waste from the Westville campus, in exchange for a service fee. Therefore, the cost of landfilling e-waste is much higher than the estimate in table 6.9. Scenario 1 is not financially sustainable, and the cost incurred will increase in future. In scenario 1, since the volume of waste disposal is relatively low, there is also a low potential to create jobs.

Table 6.9: Westville campus: scenario 1 (economic analysis)

W.R.O.S.E Scenario 1 (Economic analysis)					
Strategy	Tons/year	Cost	Revenue	Net	Job creation potential
Landfill Disposal	2.82	R 2,025.19	R 0.00	R -2,025.19	1
Landfill recovery					
Recycling					
Reuse/Resale					
Total	2.82	R 2,025.19	R 0.00	R -2,025.19	

Environmental sustainability

In scenario 1, there is a potential to generate a significant amount of greenhouse gases (see table 6.10). The greenhouse gases generated in scenario 1 originates primarily from the transportation of the waste (The detailed calculation can be seen in appendix E9). In scenario 1, a significant amount of heavy metals enter the landfill site (as shown in table 6.2). According to Xavier et al. (2019), e-waste landfilling can have severe consequences on the environment. The heavy metals in e-waste when released create toxic leachate, that affects the balance of the landfill (methane production) and adversely affects the fauna and flora in the nearby area (Xavier. et al., 2019).

Table 6.10: Westville campus: scenario 1 (environmental analysis)

W.R.O.S.E Scenario 1 (Emissions analysis)					
Strategy	Carbon emissions (Kg)		Toxic emissions(Kg)		
	C02	CH3	Cadmium	Copper	Nickel
Landfill Disposal	113.65		21.02	312.05	73.13
Landfill recovery					
Recycling					
Reuse/Resale					
Total	113.65		21.02	312.05	73.13

Social sustainability

Scenario 1, requires little public participation as waste generators (UKZN) have to just place the waste at a central collection point, where it is to be collected.

E-waste if left undisturbed poses no significant problems, however many landfill sites have frequent heavy compaction (via track-type dozer), this activity easily breaks e-waste and allows the heavy metals to be released (Gutberlet & Uddin, 2017).

In reference to chapter 2.12.3, e-waste is often targeted by waste pickers for valuable metals and components (Gutberlet & Uddin 2017). According to Langa (2019), the waste pickers primarily target garbage refuse bags (usually at the source of waste generation). However, waste at UKZN is often stored in a secure area (inside campus property) there is a low potential of access to waste pickers (Langa, 2019).

Therefore, the e-waste from UKZN will be targeted by the waste pickers at the landfill site (Gutberlet & Uddin, 2017). According to Neto, et al. (2019) e-waste pickers often are not technically trained to dismantle e-waste and often just break off the value materials, this improper processing of e-waste can release many of the toxic substances in the e-waste (see chapter 2.12).

Institutional sustainability

With reference to chapter 2.14, there are several key legislations put into place to ensure safe and sustainable waste management in South Africa. The legislations were established to enforce the correct management and disposal of waste:

- The National Environmental Management Act No. 107 of 1998 (NEMA).

- The Environment Conservation Act No. 73 of 1989 (ECA).
- The White Paper on Integrated Pollution and Waste Management (2000).
- The National Waste Management Strategy (NWMS 2008).

However, the above legislation only accounts for general and inert waste and e-waste (as contains several toxic materials, see chapter 2.6) cannot be disposed of in accordance with the above. At present, there is no specific (enforceable) legislation in South Africa that is centred around the sustainable management and disposal of e-waste.

In chapter 5.2, the majority of participants agreed that there was a need for an e-waste management strategy and that it was important to have a sustainable e-waste management plan. According to chapter 5.3, The main reason why the participants of the study agreed to the creation of an IWMP is that there were aware of the toxic material found in e-waste and the impact it had on human health and the environment. The findings of chapter 5, indicate that there is demand for the creation of an IWMP and legislations for the sustainable management and safe disposal of e-waste in UKZN.

6.3.2 Westville campus scenario 2: Unsorted e-waste in the combined waste stream is collected by a contractor, the contractor separates e-waste from the stream and sells it to a recycling agent.

In scenario 2, as shown in figure 6.6, unsorted e-waste is collected by a contractor. UKZN pay for the waste collection. The contractor separates e-waste from the waste stream and sells it to a recycling agent. The remainder of the waste is to be disposed into a landfill site. In scenario 2, a substantial amount of the e-waste is diverted from landfills.

In a study by Andarani & Goto (2012) the typical e-waste recycling facility can produce between 5-10 % of residual waste. In this study 10 % residual waste is assumed. Therefore 10% of the total e-waste will be disposed into a landfill.

In scenario 2, the e-waste is mixed in with the waste stream, therefore a material recovery operation must be undertaken by the contractor. The e-waste generated by UKZN is typically large items (see chapter 5), therefore the e-waste can easily be removed by hand. Therefore, there is no need to create a material recovery facility to separate the e-waste.

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL

W.R.O.S.E Scenario 1

Waste material or waste fraction	Landfill Disposal (Kg)	Landfill recovery (Kg)	Recycling (Kg)	Reuse/Resale (Kg)
PC	2386.7			
Printers	138			
Projectors	6.48			
Air conditioners	286			
Sum total	2,817.18			
			Total	2,817.18

Figure 6.6: Westville campus (scenario 2)

Economic sustainability

Scenario 2 has the potential to be economically sustainable and potentially profitable for the contractor. In scenario 2, the main cost for the contractor is the transportation and separation of the e-waste from the mixed stream. The contractor has two main sources of revenue from this scenario, the first is the collection charge received from UKZN and the second is from the sale of the e-waste to the recycler.

E-waste recycling, as shown in table 6.11, has a significant profit margin, approximately 90% profit margin. Therefore, the initial cost of separating the e-waste from the mixed stream may be lucrative as the contractor can sell the e-waste at a premium. In scenario 2, there is potential to create 3 permanent jobs (as shown in table 6.11).

Table 6.11: Westville campus: scenario 2 (economic analysis)

W.R.O.S.E Scenario 2 (Economic analysis)					
Strategy	Tons/year	Cost	Revenue	Net	Job creation potential
Landfill Disposal	0.28	R 202.52	R 0.00	R -202.50	1
Landfill recovery					
MRF					
Recycling	2.54	R 6,273.53	R174,417.63	R168,144.11	2
Reuse/Resale					
Total	2.82	R6,273.53	R174,417.63	R168,144.11	3

Environmental sustainability

In scenario 2, the majority of e-waste is diverted from landfill's sites. The recycling of e-waste does produce some waste (see chapter 2.11), most of this is from the unrecyclable plastics and the toxic materials (such as cadmium and lead) found in the components (see chapter 2.12). The toxic material is made first inert by using stabilization agents and then disposed of. The above ensures that e-waste will not endanger the health of humans and the environment.

There are two sources of greenhouse gas emission in scenario 2, the first is the transportation of e-waste and the second is the recycling of e-waste. Most of the gas emissions originate from the transportation of e-waste (see appendix E). Table 6.12 show the summary of the total gas emissions from scenario 2.

The most common method of e-waste recycling, in KwaZulu natal where the study is based, is pyrolysis (see chapter 3.19.3). While there are some gas emissions from pyrolysis, this volume is significantly less than producing virgin materials (see chapter 2.10.3). The recycling of e-waste reduces the consumption of virgin material, as the recycled, materials re-enter the manufacturing cycle to meet consumer demand.

Table 6.12: Westville campus: scenario 2 (environmental analysis)

W.R.O.S.E Scenario 2 (Emissions analysis)					
Strategy	Carbon emissions		Toxic emissions (Kg)		
	C02	CH3	Cadmium	Copper	Lead
Landfill Disposal	11.365	0	2.1024656	31.20479138	7.313107
Landfill recovery					
Recycling	132,402.75	158,883.30	21.02	312.05	73.13
Reuse/Resale					
	132,414.12	158,883.30	23.13	343.25	80.44

Social sustainability

In scenario 2, the waste Is collected by the contractor; therefore, no source separation is required by UKZN staff, the waste has to just be placed at the relative collection points. The relative simplicity of this scenario (for UKZN) will aid the long term sustainability of this scenario. The recycling of e-waste will ensure the toxic material found in e-waste will affect human health and the environment.

Institutional sustainability

There is no specific legislation regarding e-waste management in South Africa. With reference to chapter 2.14.1, there are several guidelines on safe and sustainable e-waste management. The most well know of these guides are:

- The Basel convention (2011).
- The European union's WEEE directive (2012/19/EU).
- Solving the e-waste problem (STEP) (2012).

However, these guidelines are based on the global e-waste problem and not specified in the South African context. The above guidelines are targeted around consumer e-waste and stopping the transboundary movement (see chapter 2.4.2) of e-waste, these guidelines will not be effective in the case of an educational facility such as UKZN.

There are South African based organisations such as eWASA that focus on e-waste management in a South African context (see chapter 2.14.3) however these guidelines focus on consumer e-waste and will not be effective in the case of an educational facility such as UKZN.

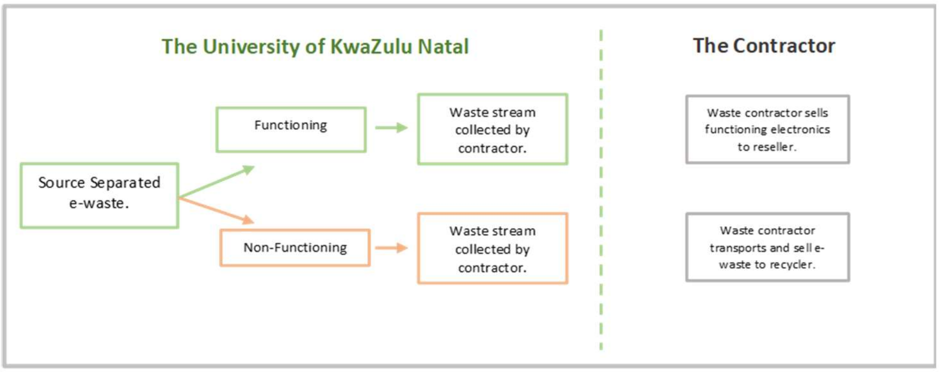
Therefore, there is a need for an e-waste management plan for an educational institute such as UKZN. The findings of chapter 5, provide support for the above and the need for the creation of an IWMP and legislations for the sustainable management and safe disposal of e-waste in UKZN.

6.3.3 Scenario 3: Source separated e-waste, is sold to the contractor. The contractor refurbishes the functioning electronics and sells to resale agent. The contractor sells the non-functioning electronics to a recycler.

In scenario 3, as shown in figure 3.7, a holistic, integrated waste management solution is adopted. The e-waste is to be separated at the source and be divided based on functionality. The e-waste is to be source-separated at UKZN, and then sold to the contractors. According to chapter 5, 10 % of electronics are in poor condition and are to be landfilled, 10% are in moderate condition and are to be recycled and 80% are in excellent condition and are to be refurbished and reused.

The contractors are to refurbish the functioning electronics and sell to a resale agent. The electronics that are functioning are to be refurbished and reused, as a large part of South Africa does not have access to technology, and they will benefit from access to more affordable electronics. The non-functioning e-waste will be sold by the contractor to a recycling agent. Most recyclers in South Africa do not have the capacity to recycle metals and plastics, therefore the recyclables are only extracted by recyclers and sold to smelters and to remanufacturers (see chapter 2.14).

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL
W.R.O.S.E Scenario 3



Waste material or waste fraction	Landfill Disposal (Kg)	Landfill recovery (Kg)	Recycling (Kg)	Reuse/Resale (Kg)
PC	1909.36		238.67	238.67
Printers	110.4		13.8	13.8
Projectors	5.184		0.648	0.648
Air conditioners	228.8		28.6	28.6
Sum total	2253.744		281.718	281.718
			Total	2817.18

Figure 6.7: Westville campus (Scenario 3)

In scenario 3, approximately 90% of e-waste is diverted from landfill. The majority of the 10% being disposed into landfills is from the desktops (Mainly the plastic monitor case) printers and units, mainly the plastic fraction as it is not economical to recycle.

Economic sustainability

In scenario 3, most of the electronics that are to be reused/resold, are in excellent condition and little maintenance and repair work is required; therefore, there is a great potential to generate revenue from this scenario (as shown in table 6.13).

According to the e-waste recyclers (See appendix E), there is no collection charge for e-waste; there is no compensation in return. The revenue generated from e-waste recycling is used to cover all the costs and overheads. However, as shown in table 6.13, there is a large profit margin, approximately 90% profit margin for the e-waste recycler, and therefore, e-waste recycling is an economically sustainable option. In scenario 3, there is potential to create an additional 7 permanent jobs (as shown in table 6.13), most of which are from the resale of electronics.

Table 6.13: Westville campus: scenario 3 (economic analysis)

W.R.O.S.E Scenario 3 (Economic analysis)					
Strategy	Tons/year	Cost	Revenue	Net	Job creation potential
Landfill Disposal	0.28	R 202.52	R 0.00	R -202.50	1
Landfill recovery					
Recycling	0.28	R 627.35	R 17,441.76	R 16,814.41	1
Reuse/Resale	2.25	R 0.00	R 3,910,320.00	R 3,910,320.00	3
Total	2.82	R 829.87	R 3,927,761.76	R 3,926,931.91	5

Environmental sustainability

In scenario 3, most e-waste from UKZN is diverted from landfill sites (90%); therefore, there is a substantial decrease in the amount of toxic material entering landfill sites from UKZN.

There are two sources of greenhouse gas emission in scenario 3, the first is the transportation of e-waste and the second is the recycling of e-waste (see Appendix E9 for detailed calculations). Most of the gas emissions in scenario 3 originate from the transportation of the e-waste (see Appendix E9). Table 6.14 shows a summary of the total gas emissions from scenario 3.

For the purpose of this study, pyrolysis is assumed to be used for all e-waste recycling, as pyrolysis is the most common method of e-waste recycling in KwaZulu Natal (see table 3.19). While there are some gas emissions from pyrolysis, this volume is significantly less than producing virgin materials (see chapter 2.10.3). In addition, recycling of e-waste, prevents the consumption of virgin material, as the recycled, materials re-enter the manufacturing cycle (see chapter 2.8).

The waste material is made first inert by using stabilization agents and then disposed of (see chapter 2.10). The reuse/resale of electronic prevents the consumption of virgin material to manufacture new electronics, therefore mitigating the harmful emissions during production (see chapter 2.10.3). The above ensures that e-waste will not endanger the health of humans and the environment.

Table 6.14: Westville campus: scenario 3 (environmental analysis)

W.R.O.S.E Scenario 3 (Emissions analysis)					
Strategy	Carbon emissions (Kg)		Toxic emissions (Kg)		
	C02	CH3	Cadmium	Copper	Lead
Landfill Disposal	30.94		1.40	16.25	3.61
Landfill recovery					
Recycling	26801.93	32162.31	11.23	129.98	0.55
Reuse/Resale					
Total	26832.86	32162.31	12.63	146.23	4.17

Social sustainability

In scenario 3, the e-waste is required to be sorted at the source by the waste generator. However, at the University of KwaZulu Natal, the e-waste is stored separately from the regular waste; therefore, there will be no additional labour required. UKZN will leave all separated e-waste at collection points, for the contractor to collect.

The reuse and recycling of the e-waste will substantially reduce the amount of toxic material in e-waste being disposed of by UKZN into landfill sites. The reduction in e-waste being disposed of will benefit human health (in particular the waste pickers at the landfill site) and the environment (landfill sites in particular).

Institutional sustainability

There is no specific legislation regarding e-waste management in South Africa. With reference to chapter 2.14.1, there are several guidelines on safe and sustainable e-waste management. The most well know of these guides are:

- The Basel convention (2011)
- The European union's WEEE directive (2012/19/EU)
- Solving the e-waste problem (STEP) (2012)

However, these guidelines are not based on the global e-waste problem and not specified in the South African context. The above guidelines are targeted around consumer e-waste and stopping the transboundary movement (see chapter 2.4.2) of e-waste, these guidelines will not be effective in the case of an educational facility such as UKZN.

There are South African based organisations such as eWASA that focus on e-waste management in a South African context (see chapter 2.14.3) however these guidelines focus

on consumer e-waste and will not be effective in the case of an educational facilities such as UKZN.

Therefore, there is a need for e-waste management plan for an educational institute such as UKZN. The findings of chapter 5, provide support for the above and the need for the creation of an IWMP and legislations for the sustainable management and safe disposal of e-waste in UKZN.

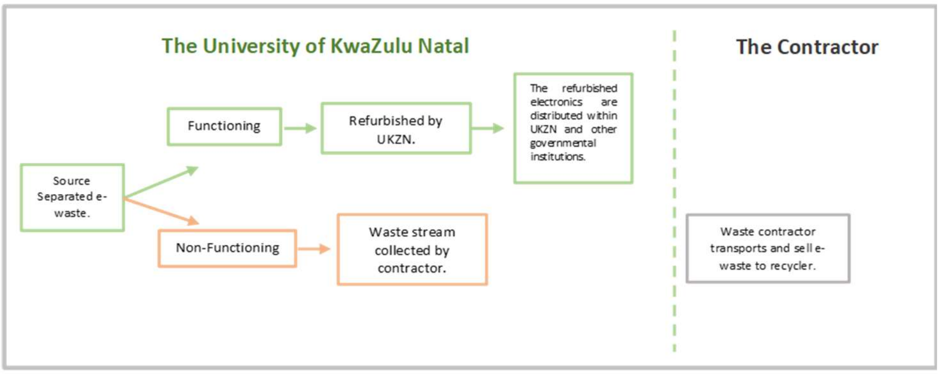
6.2.4. Source separated e-waste. The functioning e-waste to be refurbished by UKZN and be reused internally or by another government agent. The non-functioning e-waste is to be sold by the contractor to a recycling agent.

In scenario 4 (as shown in figure 6.8), a holistic, integrated waste management solution is adopted. The e-waste is to be separated at the source and be divided based on functionality. The e-waste is to be source-separated at UKZN, and the non-functioning fraction is sold to the contractors. According to chapter 5, 10 % of electronics are in poor condition and are to be landfilled (made inert before disposal), 10% are in moderate condition and are to be recycled and 80% are in excellent condition and are to be refurbished and reused.

The non-functioning e-waste will be sold by the contractor to a recycling agent. Most recyclers in South Africa do not have the capacity to recycle metals and plastics, therefore the recyclables are only extracted by recyclers and sold to smelters and to remanufacturers (see chapter 2.14). The functioning electronics are to be refurbished, the functioning electronics are to be reused internally by UKZN or by another government agent. The electronics that are functioning are to be refurbished and reused, as a large part of South Africa does not have access to technology, and they will benefit from access to more affordable electronics.

WASTE & RESOURCE OPTIMIZATION STATEGY EVALUATION MODEL

W.R.O.S.E Scenario 4



Waste material or waste fraction	Landfill Disposal (Kg)	Landfill recovery (Kg)	Recycling (Kg)	Reuse/Resale (Kg)
PC	1909.36		238.67	238.67
Printers	110.4		13.8	13.8
Projectors	5.184		0.648	0.648
Air conditioners	228.8		28.6	28.6
Sum total	2253.744		281.718	281.718
			Total	2817.18

Figure 6.8: Westville campus (scenario 4)

In scenario 4, approximately 90% of e-waste is diverted from landfill. The majority of the 10% being disposed into landfills is residual waste from recycling operations.

Economic sustainability

In scenario 4, most electronics that are to be reused/resold, are in excellent condition and little maintenance and repair work is required; therefore, there is a great potential to generate revenue from this scenario (as shown in table 6.15).

According to the e-waste recyclers (See appendix E), there is no collection charge for e-waste; there is no compensation in return. The revenue generated from e-waste recycling is used to cover all the costs and overheads. However, as shown in table 6.15, there is a large profit margin, approximately 90% profit margin for the e-waste recycler, and therefore, e-waste recycling is an economically sustainable option.

In scenario 4, there is potential to create additional 7 permanent jobs (as shown in table 6.15), most of which are from the resale of electronics.

Table 6.15: Westville campus: scenario 4 (economic analysis)

W.R.O.S.E Scenario 4 (Economic analysis)					
Strategy	Tons/year	Cost	Revenue	Net	Job creation potential
Landfill Disposal	0.62	R 442.81	R 0.00	R -422.81	1
Landfill recovery					
Recycling	0.62	R 1,370.82	R 12,193.57	R 10,822.76	1
Reuse/Resale	4.92	R 0.00	R 1,829,680.00	R 1,829,680.00	5
Total	6.16	R 1,813.63	R 1,841,873.57	R 1,840,079.94	7

Environmental sustainability

In scenario 4, most e-waste from UKZN is diverted from landfill sites (90%); therefore, there is a substantial decrease in the amount of toxic material entering landfill sites from UKZN.

There are two sources of greenhouse gas emission in scenario 3, the first is the transportation of e-waste and the second is the recycling of e-waste (see Appendix E9 for detailed calculations). Most of the gas emissions in scenario 4 originate from the transportation of the e-waste (see Appendix E9). Table 6.16 shows a summary of the total gas emissions from scenario 4.

For the purpose of this study, pyrolysis is assumed to be used for all e-waste recycling, as pyrolysis is the most common method of e-waste recycling in KwaZulu Natal (see table 3.19). While there are some gas emissions from pyrolysis, this volume is significantly less than producing virgin materials (see chapter 2.10.3). In addition, recycling of e-waste, prevents the consumption of virgin material, as the recycled, materials re-enter the manufacturing cycle (see chapter 2.8).

The waste material is made inert first by using stabilization agents and then disposed of (see chapter 2.10). The reuse/resale of electronics prevents the consumption of virgin material to manufacture new electronics, therefore mitigating the harmful emissions during production (see chapter 2.10.3). The above ensures that e-waste will not endanger the health of humans and the environment.

Table 6.16: Westville campus: scenario 4 (environmental analysis)

W.R.O.S.E Scenario 4 (Emissions analysis)					
Strategy	Carbon emissions (Kg)		Toxic emissions (Kg)		
	C02	CH3	Cadmium	Copper	Lead
Landfill Disposal	30.94	0.00	1.40	16.25	3.61
Landfill recovery					
Recycling	24.81	0.00	11.23	129.98	0.55
Reuse/Resale					
Total	55.74	0.00	12.63	146.23	4.17

Social sustainability

In scenario 4, the e-waste is required to be sorted at the source by the waste generator. However, at the University of KwaZulu Natal, the e-waste is stored separately from the regular waste; therefore, there will be no additional labour required. UKZN will leave all separated e-waste at collection points, for the contractor to collect.

The reuse and recycling of the e-waste will substantially reduce the amount of toxic material in e-waste being disposed of by UKZN into landfill sites. The reduction in e-waste being disposed of will benefit human health (in particular the waste pickers at the landfill site) and the environment (landfill sites in particular).

Institutional sustainability

There is no specific legislation regarding e-waste management in South Africa. With reference to chapter 2.14.1, there are several guidelines on safe and sustainable e-waste management. The most well know of these guides are:

- The Basel convention (2011)
- The European union's WEEE directive (2012/19/EU)
- Solving the e-waste problem (STEP) (2012)

However, these guidelines are based on the global e-waste problem and not specified in the South African context. The above guidelines are targeted around consumer e-waste and stopping the transboundary movement (see chapter 2.4.2) of e-waste, these guidelines will not be effective in the case of an educational facility such as UKZN.

There are South African based organisations such as eWASA that focus on e-waste management in a South African context (see chapter 2.14.3) however these guidelines focus

on consumer e-waste and will not be effective in the case of an educational facility such as UKZN.

Therefore, there is a need for an e-waste management plan for an educational institute such as UKZN. The findings of chapter 5, provide support for the above and the need for the creation of an IWMP and legislations for the sustainable management and safe disposal of e-waste in UKZN.

6.3.5 Selection of IWMP strategy for UKZN Westville

The design of IWMP must consider the economic feasibility and the sustainability of the strategy for both the short and the long term.

The best scenario in the short term is to implement scenario 3. In scenario 3, the functioning fraction (80% of the waste stream) of the e-waste will be refurbished and resold, and the non-functioning fraction will be recycled (20% of the waste stream). UKZN sell the e-waste to contractors who are then responsible for the management and disposal of the e-waste. This scenario is lucrative for the contractor as there are high potential revenues.

Scenario 3 is preferred over scenario 4, as in this scenario UKZN has no responsibility in the management of the e-waste after the e-waste has been handed over to the contractor. In terms of a practicality perspective, it will be easier for UKZN to implement scenario 3 over scenario 4 as there is less investment required, in both financial and institutional means. According to Marshall & Stephenson (2020) in South Africa, only 30% of the population has access to any computer equipment (i.e., Desktop, Printers and projectors). Therefore, the refurbished electronics (which cost approximately 40-50% of new electronics) will allow many more people access to computer equipment. The e-waste recycling industry in South Africa is relatively new, and still in its infancy (only small and medium-sized facilities), therefore may not have the capacity to recycle a large volume of e-waste (see chapter 3).

In the short term, scenario 4 is both economically feasible and sustainable. In scenario 4, 90% of e-waste is diverted from landfills; this saves landfill space and prevents toxic material from entering the landfill. The potential revenue generated from this scenario offsets the cost and creates an additional 5 permanent jobs.

The best long-term solution will be scenario 2, as in the future the demand for preowned electronics will drastically decrease. The driving forces behind this rapid decrease in demand of electronics are the increased buying power of consumers (consumers having more disposable income, chapter 2.6), and sector-based growth (electronic devices becoming more economical, see chapter 2.5.2). The above factor will influence South Africa significantly as South Africa is a developing country and is expected to grow much in the future (Chapter 2.4.3).

Hence, as the demand for pre-owned electronics will decrease; therefore, the most feasible solution in the long term will be to recycle the entire e-waste stream. In the long term, optimistically the e-waste recycling industry will grow and will be able to recycle large volumes of e-waste.

The use of the above scenarios for the IWMP of Howard campus will ensure sustainable e-waste management in the short term and long term.

6.4 Sustainability Goals/Objectives

To ensure the sustainability of the proposed IWMP is valid, the IWMP will be evaluated against the circular economy's objectives, the Sustainable development goals, and the SARCHI chair's goals.

6.4.1 Circular economy goals

The selected scenario's to be implemented in the IWMP is centred around, creating a circular economy. The movement away from a linear economy (Chapter 2.7) towards a circular economy (Chapter 2.7.1) is crucial for a sustainable future. The ideology of a circular economy is to reuse today's waste as a resource in future productions. The strategy used in the selected scenarios (scenarios 2 and 3), promotes a circular economy, (as shown below). The selected strategy:

A. The recycling of e-waste:

- Prevents the loss of materials, (such as gold, silver, and copper), that once the landfill is difficult to recover. The recycling of e-wase will decrease the demand for virgin materials, conserve natural resources and promote a circular economy.
- Aids in the mitigation of price rises. The recycling and re-adding of resources back into the market will allow prices to become more stable. The efficient recycling of e-waste will ensure not only a stable market but also a more stable economy.

B. The reuse of electronics:

- This will prevent the consumption of virgin materials, as the demand for new electronics will decrease.
- The reuse of electronics will prevent many harmful emissions from being released into the environment.

6.4.2 Sustainable development goals (SDG's)

The IWMP was evaluated against the SDG's, as this will validate the social and environmental sustainability of the proposed IWMP. The SGD's, for scenario 3 and 5 are shown in table 6.17.

Table 6.17: Sustainable development goals for the proposed IWMP

Sustainable development goals (SDG's)	**Scenario 2 Recycling of e-waste**	**Scenario 3 Refurbishment and recycling**
8. Decent work Economic growth	Scenario 3 is economically sustainable (Chapter 6.2.6). The e-waste recycling industry is relatively new and has potential to grow. If scenario 3 is implemented it will have a significant impact on the economic growth, as it will generate great margins of revenue and create jobs.	In scenario 3, the refurbishment and reuse of electronics, allows more people access to electronic devices (i.e., Desktop computers). Thus, more people will become computer literate, this in turn will allow more people access to better paying jobs and this in turn will lead to economic growth.
9. Innovation	The use of multiple different waste management strategies, to create a IWMP that will utilize the majority of e-waste as a resource requires innovation (Both technical and economical)	
10. Reduce inequality	In scenario 3, there is potential to create jobs, these jobs require semi-skilled (and even no skill) labour. These jobs will aid in reducing economic inequality.	In scenario 3, the reuse/refurbishment of electronic devices (i.e., Desktop computers), will allow these devices (which are less than 50% of original price) to be accessed by people with lower income, hence reducing inequality.
12.Responsible consumption	The recycling of e-waste, reducing the consumption of virgin materials and hence promoting responsible consumption.	The refurbishment/reuse of electronics will reduce the production of new electronics and hence promote responsible consumption.
13. Climate action	The recycling of e-waste reduces the volume of harmful gases being emitted during the production of electronics.	The reuse of electronic devices will reduce the demand for new electronic device and hence reduce production. This will reduce the volume of harmful gaseous being emitted.

6.4.3 SARCHI chair goals

The SARCHI goals as set out in Chapter 2 (2.8.1), are to be met by the proposed IWMP as it will ensure the social and environmental sustainability of the proposed IWMP. The evaluation of the IWMP against SARCHI Goals is shown in table 6.18.

Table 6.18: SARCHI goals for the proposed IWMP

Summary of criteria	How does this study address the question
Where in the waste sector are, we are generating GHGs (and how much)?	In this study, the generation of Ghg's is addressed and the scenarios that generate the least amount of Ghg's were selected for the IWMP.
What technology portfolio (lowest cost option) could achieve climate stabilization for your country waste sector and geographically where should they be located to ensure maximum impact?	The e-waste management strategies implemented in the scenarios are the lowest cost options (and have the potential to generate significant revenue). The reuse/resale of electronics is a particularly important strategy
What is the best scenario for your country waste sector to achieve a low carbon economy and what would be required for end-of-life technologies, waste collection systems (transportation), consumption, etc.?	The strategy of recycling e-waste will reduce the overall emissions in the manufacturing of new electronics, as recycling produces less carbon emission than producing electronics from virgin materials.
In the Localisation of appropriate technology/infrastructure what are drivers/barriers (costs/tech feasibility) etc.	There are institutional barriers in place, however there a many organisations in place that is aware of the dangers of e-waste and are working to raise awareness with the hope of creating enforceable legislation that will ensure e-waste will be managed properly.

The proposed IWMP meets all four of the main goals set out by the SARCHI chair, and this validates the social and environmental sustainability of the scenario.

6.5 Chapter conclusion

The Proposed IWMP of the selected campuses were designed in order to be both economical and sustainable. The IWMP for the Westville campus is similar to that of the Howard campus. The reason is that both campuses have the same waste stream, and the same authority manages the campuses, therefore having the same waste management practices.

The campuses also have the same general purpose, as an education facility and require the same equipment, hence having similar waste streams.

The proposed IWMP Will divert approximately 90% of waste in the short term and 100% in the long term. The Proposed IWMP is economically feasible in both the short term and long term, with the potential to generate substantial revenue.

The IWMP is socially sustainable as it can create jobs, and it is environmentally sustainable as it prevents the harmful emission of greenhouse gases and the release of toxic material to the environment. The social and environmental sustainability is validated by the circular economy goals, the SDGs, and the SARCHI goals as the IWMP meets the standards.

Chapter 7: Review, conclusion, and recommendations

The study comprised the following components in assessing the e-waste management scenarios and strategies for the University of Kwa-Zulu Natal.

- Development of the W.R.O.S.E model, and the associated waste management strategies to manage e-waste.
- GHG emission/reduction evaluation of each scenario
- The waste was diverted from landfills, and the landfill airspace assessment was performed for each scenario.
- The economic analysis (i.e., the operating cost, the revenue generated, and the net balance) was evaluated.

This chapter summarises these results, comments on challenges, and makes recommendations based on the study results.

7.1. Summary of results

The summary of the research is shown in the flowchart below (Figure 7.1).

The waste stream of all five campuses was remarkably similar (I.e., desktops computers, printers, projectors, and air conditioning units), with the most significant contributor being desktops computers (approximately 85%).

The study (in Chapter 5) discovered that most e-waste generated at The University of KwaZulu natal was in excellent condition. The disposal was not because the electronics were broken or malfunctioning but instead became obsolete (replaced with more recent models). The main strategies utilized in designing an Integrated waste management plan (for both campuses) are recycling and refurbishment/resale. Over 90% of all e-waste generated can be diverted away from the landfill site using the strategies mentioned above.

The diversion of e-waste away from landfills (which has a hazardous nature, see chapter 2.12) will ensure environmental and social sustainability. The prevention of toxic material entering the landfills will prevent the production of toxic leachate from forming. The diversion of waste away from landfill sites will save a considerable amount of landfill space, Howard campus will save 6,2 m^3 and Westville 2.82 m^3 a year. In scenario 2 of Howard campus, there are approximately 321,623.10 Kg of CH_2 and 268,019.3 Kg of CO_2, and in Westville campus, there are approximately 158,883.30 Kg of CH_2 and 132,402.75 Kg of CO_2, while there are considerable volumes there are still much less than producing from virgin materials (Chapter 2.11). In scenario 3 the only gaseous emissions arise from the waste transportation, Howard campus 102.29 Kg of CO_2 and Westville campus 55.74 Kg of CO_2.

The Integrated waste management plan utilizes scenarios 2 and 3, and these scenarios are economically feasible in both the short term and the long term, respectively. Both scenarios have the potential to generate significant revenue, scenario 2 at Howard campus can potentially generate R 130,087.69, and scenario 3 can generate R 1 840 079,94, and Westville campus can potentially generate R59,153.00 from scenario 2 and R 798 675,91 from scenario 3. The Integrated waste management plan also can generate a significant number of jobs at Howard campus 3 jobs can be created in scenarios 2 and 7 jobs in scenario 3. In the Westville campus, 2 jobs can be created in scenarios 2 and 5 jobs in scenario 3.

The IWMP was evaluated against the goals set out by the Circular economy, the South African Research chair initiative, and the Sustainable development goals, to validate the sustainability of the Integrated waste management plan. The overall proposed solutions are both economically feasible and sustainable.

Figure 7.1: Summary of results

7.2 Challenges

The Global pandemic (Covid-19) placed many restrictions on the study. Due to the South African government's numerous restrictions, traditional research practices could not be followed. Hence the study had to modify to follow these restrictions. The most constrictive restriction was limited time in the study area(s); therefore, many alterations and assumptions were needed to be made (see Chapter 4).

The IWMP suggested in chapter 6, requires the participation of the public. The public is required to separate e-waste that is to be collected separately. In South Africa, only 15-20% of e-waste is responsibly managed; therefore, a considerable effort is required from the public to move away from disposal and storage of e-waste to more sustainable waste management practices.

To promote the sustainable management of e-waste, the IWMP must be accessible to everyone as a guideline for proper e-waste management. However, a guideline alone will not sufficiently improve e-waste management. Enforceable legislation must be created to support the strategies of the IWMP, to ensure the success of the IWMP and better e-waste management practices.

7.3. Incentives for the use of the IWMP.

The University of KwaZulu natal (UKZN) is considered the frontier for research and development, and often establishes higher standards for social responsibility and environmental conservancy than other institutions.

UKZN is known to be one of the premier authorities in sustainable development and waste management in South Africa and throughout Africa. Therefore, the practice of sustainable e-waste management will influence many other institutions and organizations to implement proper e-waste management practices.

The University of KwaZulu Natal has acknowledged that responsibility and has created a program known as “Green UKZN” which aims to promote waste minimization and better waste management practices. This study suggests an IWMP that when implemented will minimise the volume of waste generated and entering the landfill site. The University of

KwaZulu Natal has various grounds to support the implementation of the IWMP for e-waste. The incentivised grounds are economic, environmental, and social.

- **Economic:** The reuse and recycling of the e-waste that is generated at UKZN is an economically sustainable method of waste disposal. The suggested scenarios for the long term (scenario 2, recycling) and short term (scenario 3, reuse and recycling) have the potential to be economically sustainable. In both scenarios, the e-waste is sold by UKZN to the contractor, the contractor then processes the e-waste and sells it to either the recycler or the reseller. In the above scenarios, there is potential to break even or even generate a profit, which is economically better than the status quo (UKZN pay for e-waste collection and disposal).
- **Environmental:** The University of KwaZulu natal is renowned for its active role in a safe and environmentally conscious approach to waste management. Therefore, the responsible management of e-waste will be welcomed by UKZN representatives and stakeholders. The safe disposal of e-waste will prevent adverse impacts on both human health and the environment.
- **Social:** The implementation of the IWMP (recommended in this study) by an institution as large and renowned as The University of KwaZulu Natal (UKZN) will promote awareness of sustainable e-waste management. In addition, the endorsement of sustainable e-waste management by UKZN will serve as an example to other institutions and organizations, of how e-waste can be managed in a safe and sustainable manner.

The above reasons can provide a substantial argument can for the adoption of the IWMP suggested in this study.

7.4 Recommendations for future research

The following recommendations are suggested for future studies:

1. In this study of the University of Kwa-Zulu natal, a selected waste stream was used to draw conclusions, only the most common electronics found in computer laboratories (see chapter 3). Therefore, many e-waste sources were omitted (i.e., lecture venues, staff office and onsite shops) and the waste stream were limited, and items such as lighting fixture, switches, additional monitors and refrigerator equipment.
2. A future study should be done to create an IWMP for the campuses omitted from this study (PMB campus, medical school campus and Edgewood campus).
3. A future study should use a different study area, other than an educational institute, such as an office park or a residential area, to evaluate how the result differs across the different study areas.
4. A future study should focus more on the social aspects of e-waste management to further improve e-waste management.

The study concluded that the optimal scenarios for e-waste management at the University of KwaZulu natal are scenarios 3 and 5. These scenarios produce the least GHG's, are economically sustainable and divert the largest volumes of e-waste away from the landfill sites. The University of KwaZulu Natal generates a significant volume of e-waste; however, this will significantly grow in the future far more e-waste than that stated in this study, as the university expands and grows.

The IWMP is evaluated against the Circular economy's sustainability goals, the SARCHI chair and the SDG’s, therefore ensuring it is both socially and environmentally sustainable. The IWMP if applied as directed, will ensure the safe and proper management of e-waste.

The W.R.O.S.E model's application has not to be performed as it was done in this study, (for any institution that was not a municipality) with future studies and persistence W.R.O.S.E model can be further adapted to solve more waste management problems.

Chapter 8: References

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Chapter 9: Appendices

Appendix A: Literature review

Table A1: Ten different categories of e-waste on the basis of European WEEE directives 2012/19/EU (Forti, et al., 2018).

UNU-Key	Waste category	Equipment (Examples)	Label
1	Major household gadgets	Air conditioner, dish washer, refrigerator, washing machines, microwave oven etc.	Large HH
2	Minor household gadgets	CD and DVD players, video game consolers, alarm clock, television, grinder–juicer–mixer, electrical kettles and electric chimneys	Small HH
3	IT and telecommunication gadgets	LAN, modems, mobile phones, landline phones, printers and communication satellite	ICT
4	User gadgets	Radio receivers, television sets, MP3 players, video recorders, DVD players, digital cameras, camcorders, personal computers,	CE
5	Illumination gadgets	Ballast lamp, halogen, neon, LED and compact fluorescent lamps	Lighting
6	Electrical and electronics apparatus	Vacuum tubes, transistors, diodes, integrated circuits, wires, motors, generators, etc.	E and E tools
7	Toys, leisure and sports gadgets	Batteries in cars, trains, buses and aeroplanes etc.	Toys
8	Medical devices	Medical thermometers and biomedical engineering instruments	Medical equipment
9	Monitoring and control instruments	Relays, thermostat and microcontrollers	M and C
10	Automatic dispensers	Automatic soap dispenser, automatic water dispenser, automatic spray dispenser etc.	Dispensers

Table A2: detailed description of the UNU product classification and its correlation to other e-waste classifications based on European WEEE directives 2012/19/EU (Forti, et al., 2018).

UNU Key	Description	EEE Category under EU- 10
0001	Central heating (household installed)	Large household appliances
0002	Photovoltaic panel	Large household appliances/ consumer equipment
0101	Professional heating & ventilation (exl cooling equipment)	Large household appliances
0102	Dishwasher	Large household appliances
0103	Kitchen equipment (large furnaces, ovens, cooking equipment)	Large household appliances
0104	Washing machines (include combined dryers)	Large household appliances
0105	Dryers (wash dryers, centrifuges)	Large household appliances
0106	Household heating & ventilation (e.g., hoods, ventilators and space heaters)	Large household appliances
0109	Freezers	Large household appliances
0111	Air conditioners (household installed and portable)	Large household appliances
0112	Other cooling equipment (e.g., Dehumidifiers, heat pump dryers)	Large household appliances
0113	Professional cooling equipment (large air conditioner, cooling display)	Large household appliances
0114	Microwaves (incl. combined, excl. grills)	Large household appliances
0201	Other small household equipment (e.g., small ventilators, irons, clocks, adapters)	Small household appliances
0202	Equipment for food preparation (e.g., toaster. Grills, frying pans)	Small household appliances
0203	Equipment for hot water preparation (e.g., coffee, tea, water cookers)	Small household appliances
0204	Vacuum cleaner (excl. professional)	Small household appliances
0205	Personal care equipment (e.g. toothbrushes, hairdryers, razors)	Small household appliances

0301	Small IT equipment (e.g., Routers, keyboards, external drives & accessories)	IT and telecommunications equipment
0302	Desktop PC's (exl. Monitors)	IT and telecommunications equipment
0303	Laptops (incl. tablets)	IT and telecommunications equipment
0304	Printers (e.g., scanners, multi-functional, faxes)	IT and telecommunications equipment
0305	Telecommunications equipment (e.g., cordless phones, answering machines)	IT and telecommunications equipment
0306	Mobile phones (incl. smart phones)	IT and telecommunications equipment
0307	Professional it equipment (e.g. servers, routers, data storage, copiers)	IT and telecommunications equipment
0308	Cathode ray tube monitors	IT and telecommunications equipment
0309	Flat display panel monitors (LCD, LED)	IT and telecommunications equipment
0401	Small consumer electronics (e.g., headphones, remote controls)	Consumer equipment
0402	Portable audio & video (e.g., MP3, e-readers, car navigation)	Consumer equipment
0403	Musical instruments, radio, HI-FI (incl. audio sets)	Consumer equipment
0404	Video (e.g., video recorders, DVD, Blue-ray, set boxes)	Consumer equipment
0405	Speakers	Consumer equipment
0406	Camera's (e.g., camcorders, photo & digital still camera)	Consumer equipment
0407	Cathode ray tube TV's	Consumer equipment
0408	Flat display panel TV's (LCD, LED, Plasma)	Consumer equipment
0501	Small lighting equipment (exl. LED & incandescent)	Lighting equipment
0502	Compact florescent lamps (incl. retrofit & non-retrofit)	Lighting equipment
0503	Straight tube fluorescent lamps	Lighting equipment
0504	Special lamps (e.g., professional mercury, high- & low-pressure sodium)	Lighting equipment
0505	LED lamps (incl. retrofit LED lamps)	Lighting equipment
0506	Household luminaries (incl. household incandescent)	Lighting equipment
0507	Professional luminaries (offices, public space, industry)	Lighting equipment

0601	Household tools (e.g., drills, saws, high pressure, cleaners)	Electrical and electric equipment
0602	Professional tools (e.g., welding, soldering)	Electrical and electric equipment
0701	Toys (e.g., racing cars sets, electric trains, music toys, biking computers, drones)	Toys
0702	Game consoles (e.g., Xbox, ps4, Wii)	Toys
0703	Leisure equipment (e.g., sports equipment, electric bikes, juke boxes)	Toys
0801	Household medical equipment (e.g., thermometers, blood pressure meters)	Medical devices
0802	Professional medical equipment (e.g., hospital, dentist, diagnostics)	Medical devices
0901	Household monitoring & control equipment (e.g., alarm, smoke detector, exl. Screens)	Monitoring and control instruments
0902	Professional monitoring & control equipment (e.g., laboratory, control panels)	Monitoring and control instruments
1001	Non-cooled dispenser (e.g., vending, hot drinks, tickets, money)	Automatic dispensers
1002	Cooled dispensers (e.g., cooldrinks)	Automatic dispensers

Table A3: Indication of average weight for EU-28 (Kg/piece) (United Nations University, 2018)

UNU-KEY	**Year of manufacturing of product**					
	1995	**2000**	**2005**	**2010**	**2015**	**2016**
0001	30.85	30.85	30.85	30.85	30.85	30.85
0002	17.00	17.00	17.00	17.00	17.00	17.00
0101	124.61	124.61	124.61	124.61	124.61	124.61
0102	49.35	47.62	45.46	43.30	43.30	43.30
0103	41.86	43.52	45.59	47.66	47.66	47.66
0104	69.36	70.27	71.40	72.54	72.54	72.54
0105	38.27	40.47	43.23	45.98	45.98	45.98
0106	12.14	12.14	12.14	12.14	12.14	12.14
0108	33.59	35.65	38.22	40.79	40.79	40.79
0109	43.59	43.73	43.91	44.09	44.09	44.09
0111	26.70	26.70	26.70	26.70	26.70	26.70
0112	41.70	41.70	41.70	41.70	41.70	41.70
0113	90.00	95.74	102.92	110.10	110.10	110.10
0114	16.34	18.21	20.56	22.90	22.90	22.90
0201	1.30	1.21	1.10	0.99	0.99	0.99
0202	3.27	3.27	3.27	3.27	3.27	3.27
0203	1.89	1.89	1.89	1.89	1.89	1.89
0204	4.88	5.17	5.52	5.88	5.88	5.88
0205	0.55	0.55	0.55	0.55	0.55	0.55
0301	00.65	0.58	0.49	0.40	0.40	0.40
0302	10.31	9.87	9.32	8.77	8.77	8.77
0303	4.50	4.14	3.68	2.13	1.26	1.26
0304	7.00	7.95	9.13	10.32	10.32	10.32
0305	0.82	0.71	0.58	0.45	0.45	0.45
0306	0.12	0.11	0.10	0.09	0.09	0.09
0307	40.00	40.00	40.00	40.00	40.00	40.00
0308	14.60	16.71	19.36	22.00	22.00	22.00
0309	5.00	5.14	5.32	5.50	5.50	5.50
0401	0.39	0.39	0.39	0.39	0.39	0.39
0402	0.40	0.35	0.29	0.23	0.23	0.23
0403	4.15	4.03	3.88	3.73	3.73	3.73
0404	3.51	3.51	3.51	3.51	3.51	3.51
0405	3.00	2.75	2.45	2.14	2.14	2.14
0406	1.00	0.80	0.54	0.29	0.29	0.29
0407	25.00	27.34	30.27	33.20	33.20	33.20
0408	7.00	9.20	11.95	14.70	10.20	10.20
0501	0.09	0.09	0.09	0.09	0.09	0.09
0502	0.08	0.08	0.08	0.08	0.08	0.08
0503	0.11	0.11	0.11	0.11	0.11	0.11
0504	0.08	0.08	0.08	0.08	0.08	0.08
0505	0.08	0.08	0.08	0.08	0.08	0.08

0506	0.45	0.45	0.45	0.45	0.45	0.45
0507	2.67	2.67	2.67	2.67	2.67	2.67
0601	2.60	2.57	2.53	2.49	2.49	2.49
0602	23.17	23.17	23.17	23.17	23.17	23.17
0701	0.45	0.45	0.45	0.45	0.45	0.45
0702	0.48	0.48	0.48	0.48	0.48	0.48
0703	7.37	7.37	7.37	7.37	7.37	7.37
0801	0.18	0.18	0.18	0.18	0.18	0.18
0802	67.04	67.04	67.04	67.04	67.04	67.04
0901	0.24	0.24	0.24	0.24	0.24	0.24
0902	5.51	5.51	5.51	5.51	5.51	5.51
1001	44.00	44.00	44.00	44.00	44.00	44.00
1002	92.22	92.22	92.22	92.22	92.22	92.22

Table A4: Average life span (Years) (United Nations University, 2018)

UNU-KEYS (Data refers to 2016)	**WEIBULL LIFE-TIME DISTRIBUTION IN THE NETHERLANDS, FRANCE, AND BELGIUM**		**WEIBULL LIFE-TIME DISTRIBUTION IN ITALY**		**PROXY OF WEIBULL LIFE-TIME DISTRIBUTION USED FOR NON-EU COUNTRIES**	
	ά	β	ά	β	ά	β
0001	2.00	14.21	2.00	14.21	2.00	14.21
0002	3.50	25.00	3.50	25.00	NA	NA
0101	1.95	17.52	1.14	16.07	1.92	16.07
0102	1.64	14.20	1.37	14.28	1.79	17.13
0103	2.47	18.04	1.31	19.35	2.00	19.35
0104	2.20	15.16	2.20	13.65	1.85	13.32
0105	2.58	15.73	2.58	15.73	2.58	18.08
0106	2.00	13.47	1.22	18.80	2.00	13.47
0108	2.20	16.43	2.36	18.50	2.20	16.71
0109	2.74	24.20	1.28	18.55	1.28	18.55
0111	2.69	14.52	1.05	7.53	2.00	20.60
0112	2.39	13.56	1.29	8.29	2.36	13.36
0113	2.44	20.56	2.50	18.02	1.60	15.36
0114	1.90	14.07	1.33	9.05	2.07	17.99
0201	1.25	8.17	0.83	6.53	1.22	7.97
0202	2.06	11.22	1.15	9.57	2.02	11.02
0203	1.73	7.80	1.18	7.61	1.18	7.61
0204	1.45	10.25	1.22	10.59	1.22	10.59
0205	1.26	10.67	1.20	8.09	1.20	8.09
0301	1.25	5.91	1.30	6.15	1.30	6.15
0302	1.58	8.95	1.57	8.91	1.80	10.33
0303	1.60	6.57	1.66	6.81	1.94	8.76
0304	1.68	9.91	1.53	6.88	1.88	9.31
0305	1.24	7.22	1.32	7.70	1.32	7.70

0306	1.56	6.26	1.52	5.62	1.52	5.62
0307	1.46	7.78	1.46	7.78	1.46	7.78
0308	2.41	12.53	1.40	15.94	1.40	15.94
0309	2.33	7.39	2.33	7.39	2.30	12.18
0401	1.30	9.87	1.30	9.87	1.30	9.87
0402	0.79	7.97	1.11	5.56	1.50	10.01
0403	2.09	15.54	1.25	13.99	2.30	10.00
0404	1.67	10.47	1.14	8.33	1.14	8.33
0405	1.49	10.78	1.13	12.54	1.13	12.54
0406	1.41	8.12	1.19	6.75	1.19	6.75
0407	2.49	12.08	2.49	12.08	2.49	12.08
0408	2.01	11.75	2.01	11.75	1.88	10.95
0501	1.42	8.72	1.42	8.72	1.42	8.72
0502	1.60	8.43	1.60	8.43	NA	NA
0503	1.93	8.43	1.93	8.43	1.75	5.79
0504	1.60	6.90	1.60	6.90	1.60	6.90
0505	1.42	11.00	1.42	11.00	NA	NA
0506	2.34	16.59	2.34	16.59	2.34	16.59
0507	2.00	11.84	2.00	11.84	2.00	12.50
0601	1.82	11.28	1.82	11.28	1.77	14.98
0602	2.50	15.50	2.50	15.50	2.50	15.50
0701	1.43	4.56	1.43	4.56	1.43	4.56
0702	1.14	4.78	1.14	4.78	1.14	4.78
0703	2.40	11.56	2.40	11.56	2.40	11.56
0801	1.99	13.46	1.99	13.46	1.99	13.46
0802	2.41	13.52	2.41	13.52	2.41	13.52
0901	1.55	5.89	1.55	5.89	1.55	5.89
0902	1.92	11.56	1.92	11.56	1.92	11.56
1001	2.00	10.06	2.00	10.06	2.00	10.06
1002	2.00	10.06	2.00	10.06	2.00	15.00

Table A5: Material composition table legend (United Nations University, 2018)

Categories	Product
1	LCD Notebooks
2	LED Notebooks
3	CRT TV's
4	LCD TV's
5	LED TV's
6	CRT Monitors
7	LCD Monitors
8	LED Monitors
9	Cell Phones
10	Smart Phones
11	PV Panels
12	HDD's
13	SSD's
14	Tablets
Table A7	Air conditioning units
Table A8	Printers, facsimile, and fax machines
Table A9	Projectors
Table A10	Printed circuit board (Pcb)

Table A6: Material composition (Cucchiella, et al., 2015)

Categories	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Materials	g/unit													
Aluminium			67			242	130	130	12	2.9	1370	411	441	
Antimony	0.77	0.77	14	0.71	0.71					0.084				0.154
Arsenic	0.01	0.01												0.002
Barium	2.5	2.5				1								0.49
Beryllium										0.003				
Cadmium			0.2								0.407			
Cerium	< 0.001	< 0.001		0.005	< 0.001		< 0.001	< 0.001						< 0.001
Chromium	0.07	0.07	0.03											0.014
Cobalt	0.065	0.065							3.8	6.3				0.013
Copper	135	135	656	824	824	952			26	14	78	15	15	27
Dysprosium	0.06	0.06					0.001	< 0.001				0.06		0.012
Europium	< 0.001	< 0.001		0.008	< 0.001									< 0.001
Ferrite						483								
Gadolinium	< 0.001	< 0.001		< 0.001	0.002		< 0.001	0.002						< 0.001
Gallium		0.0016					0.003	0.003			0.119			
Glass			15760	162	216	6845	590	590		10.6	6915			
Gold	0.22	0.22		0.11	0.11	0.31	0.2	0.2	0.024	0.038		0.005	0.005	0.044
Indium	0.04	0.04		0.003	0.003		0.079	0.082			0.119			0.008
Lanthanum	< 0.001			0.007			< 0.001		1	0.6				< 0.001
Lead	5.3	5.3	1319			464	16		1					1.1
Mercury	< 0.001	< 0.001					< 0.001	0.004			0.295			< 0.001
Molybdenum	0.04	0.04					0.633	0.633		0.5				0.008

Neodymium	2.1	2.1								1.5		1		0.427
Nickel	3.6	3.6				199			1	1.5				0.722
Palladium	0.04	0.04		0.044	0.044		0.04	0.04	0.009	0.015		0.003	0.003	0.008
Plastics			8755	612	573	2481	1780	1780	63	60	1172	44	44	
Platinum	0.004	0.004								0.004				
Praseodymium	0.274	0.274			< 0.001		< 0.001			0.01		0.145		0.055
Selenium											0.199			
Silicon									5		226			
Silver	0.25	0.25		0.45	0.45	1.25	0.52	0.52	1	0.244		0.031	0.031	0.05
Steel/iron			2088			3322	2530	2530	11	8		62	62	
Tantalum	1.7	1.7												
Tellurium											0.0406			
Terbium	< 0.001			0.002			< 0.001							< 0.001
Tin			32	18	18	20	24	24	1	1	0.116			
Titanium							0.633	0.633						
Tungsten						1	0.633	0.633						
Vanadium				0.11	0.005	1								
Yttrium	0.002	0.002					0.016	< 0.001						< 0.001
Zinc	0.004	0.004	8.6						4	1	0.4			< 0.001
Percentage of critical raw materials	14	13	1	10	8	1	10	7	2	8	2	4	1	14
Percentage of precious metals	4	4	0	3	3	2	3	3	3	4	0	3	3	3

Table A7: Air conditioning unit (Almutairi, et al., 2015)

	Material	Weight percentage (%)
Non-ferrous	Aluminium	6.2
	Copper	17
Ferrous	Iron	7.13
	Stainless steel	1.47
	Steel	35.11
Plastics	High-density polyethylene (HDPE)	0.07
	Polypropylene (PP)	0.82
	Polystyrene (PS)	6.55
	Expanded polystyrene (EPS)	0.39
	High impact polystyrene (HIPS)	16.17
	Polyvinyl chloride (PVC)	4.04
	Polyamide (PA-6)	1.27
	Polybutylene terephthalate (PBT)	0.6
	Acrylonitrile butadiene styrene (ABS)	0.21
	Lacquer	0.86
	Rubber	0.17
	Other	1.93

Table A8: Printers (Lydall, et al., 2017).

	Material	Weight percentage (%)
Non-ferrous	Aluminium	19.5
	Copper	4.5
	Gold	0.07
	Nickel	0.1
	Platinum	0.05
	Silver	0.08
	Titanium	0.05
Ferrous	Iron	3
	Stainless steel	8.5
	Steel	7
Plastics	High-density polyethylene (HDPE)	12.5
	Polypropylene (PP)	4
	Polystyrene (PS)	1.2
	Expanded polystyrene (EPS)	2.3
	High impact polystyrene (HIPS)	6
	Polyvinyl chloride (PVC)	3
	Polyamide (PA-6)	0.01
	Polybutylene terephthalate (PBT)	0.01
	Acrylonitrile butadiene styrene (ABS)	0.1
	Lacquer	0.1
	Rubber	4
	Other	

Table A8: Projectors (Lydall, et al., 2017).

	Material	Weight percentage (%)
Non-ferrous	Aluminium	23.5
	Copper	16
	Gold	0.8
	Nickel	0.6
	Platinum	0.7
	Silver	0.42
	Titanium	0.02
Ferrous	Iron	2
	Stainless steel	15
	Steel	9
Plastics	High-density polyethylene (HDPE)	8
	Polypropylene (PP)	1
	Polystyrene (PS)	-
	Expanded polystyrene (EPS)	6
	High impact polystyrene (HIPS)	7
	Polyvinyl chloride (PVC)	1
	Polyamide (PA-6)	-
	Polybutylene terephthalate (PBT)	4
	Acrylonitrile butadiene styrene (ABS)	-
	Lacquer	-
	Rubber	-
	Other	-

Table A10: Typical composition of printed circuit boards (Guo, et al., 2009).

Category	18 (PCB)	Units
Materials		
Ag	3300	g/ton
Al	4.7	%
As	< 0.001	%
Au	80	g/ton
S	0.1	%
Ba	200	g/ton
Be	1.1	g/ton
Bi	0.17	%
Br	0.54	%
C	9.6	%
Cd	0.015	%
Cl	1.74	%
Cr	0.05	%
Cu	26.8	%
F	0.094	%
Fe	5.3	%
Ga	35	g/ton
MN	0.4	g/ton
Mo	0.003	%
Ni	0.47	%
Zn	1.5	%
Sb	0.06	%
Se	41	g/ton
SiO2	15	%
Sn	1	%
Te	1	g/ton
Ti	3.4	%
Sc	55	g/ton
I	200	g/ton
Hg	1	g/ton
Zr	30	g/ton
Sr	10	g/ton
# of critical raw materials		
# of precious metals		

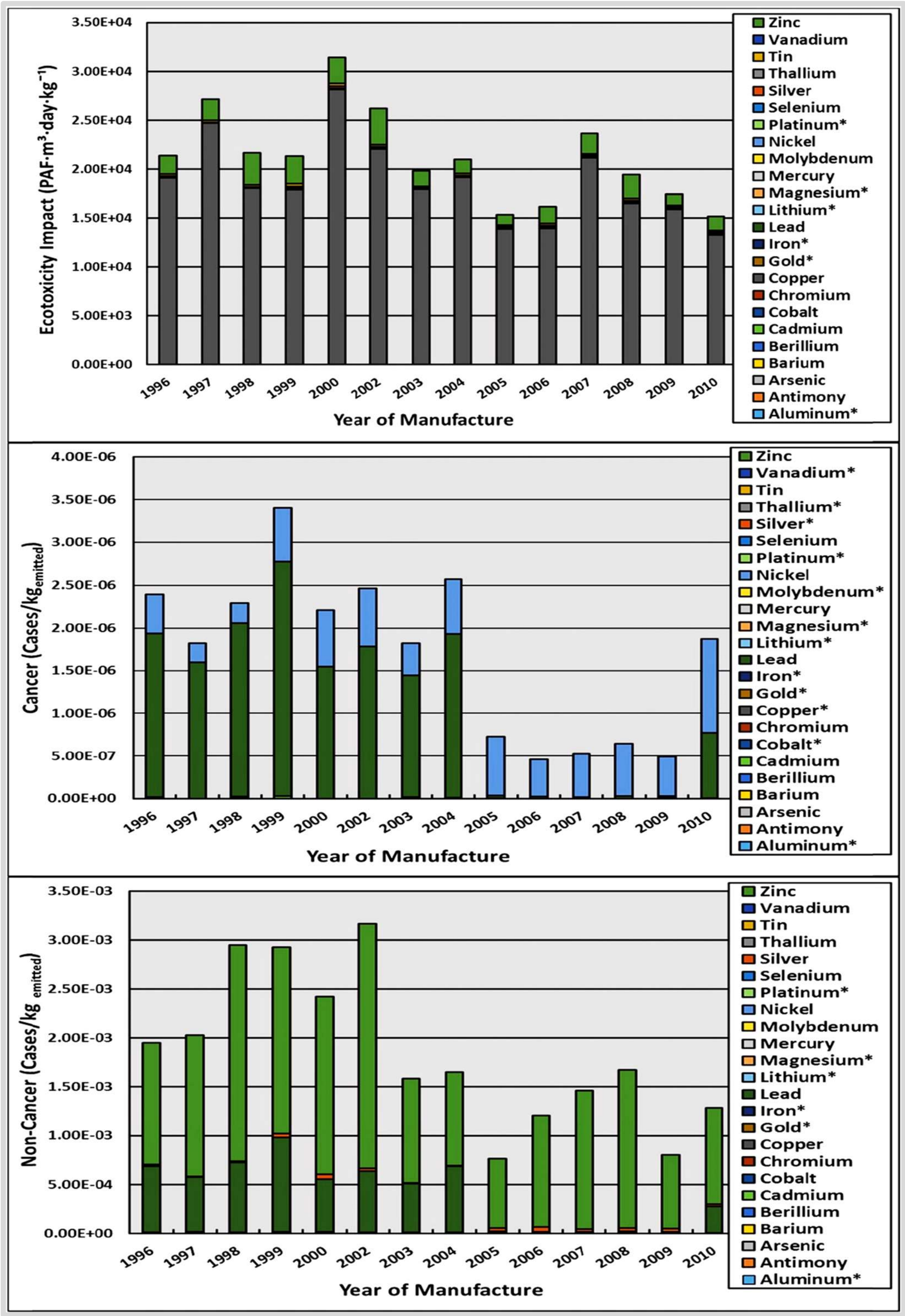


Figure A1: Results of USEtox chemical life cycle assessment modelling of the eco-toxicological (panel A), and human cancer (panel B) and non-cancer (panel C) impacts of metals identified in the Waste Printed Circuit Boards. (Abdelbasir, et al., 2018)

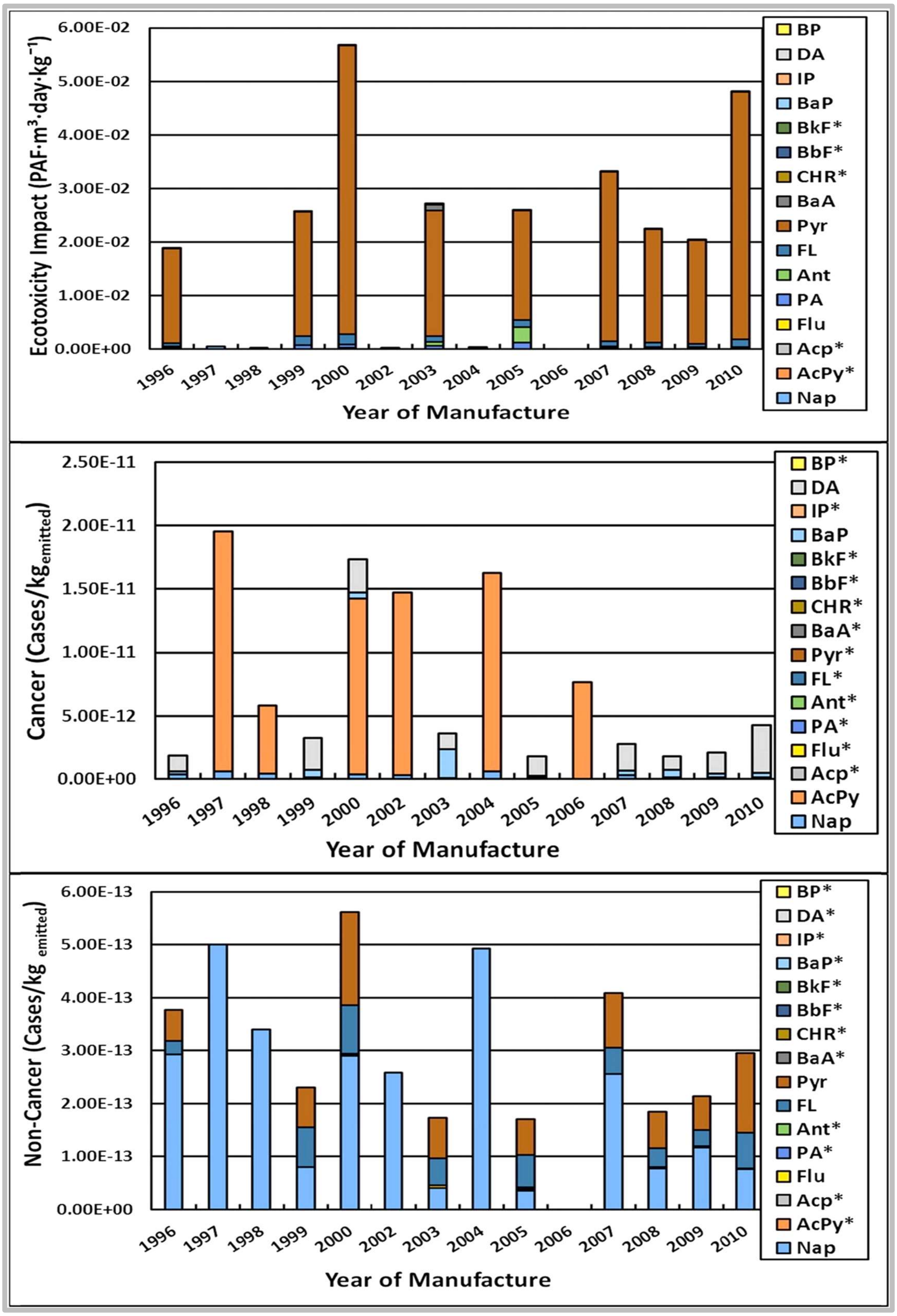
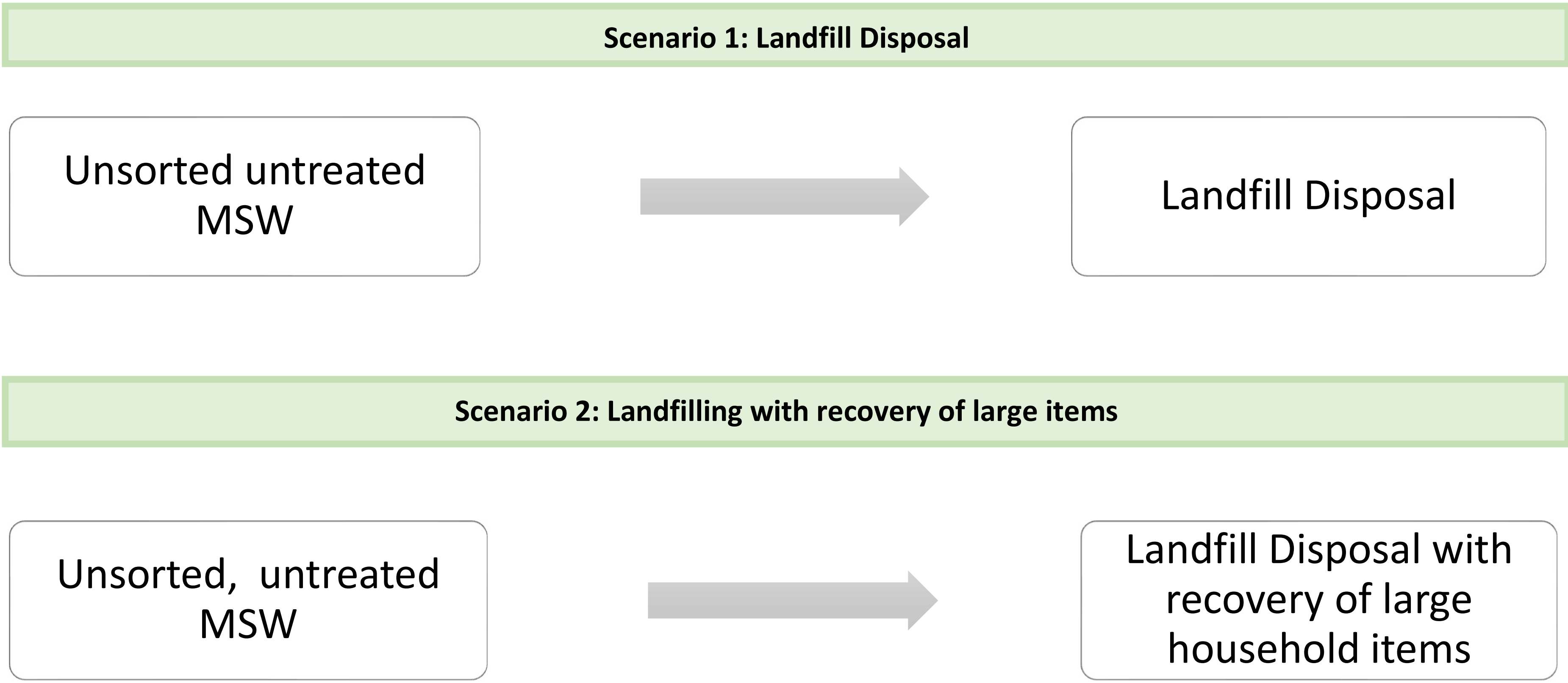
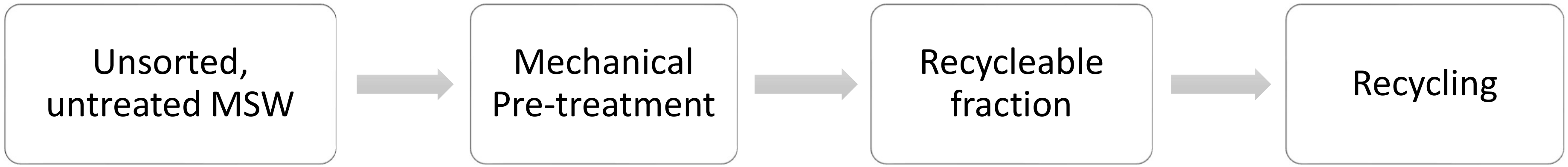


Figure A2: Results of USEtox® chemical life cycle assessment modeling of the eco-toxicological (panel A), and human cancer (panel B) and non-cancer (panel C) impacts of PAHs identified in the Waste Printed Circuit Boards (Abdelbasir, et al., 2018).

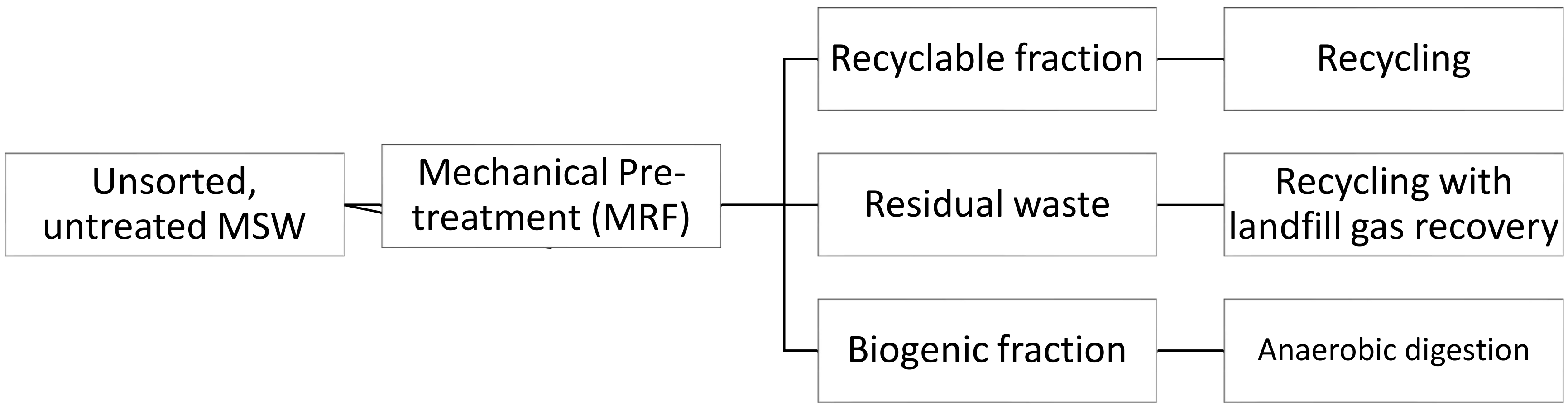
W.R.O.S.E Model (Trois & Kissoon, 2020)



Scenario 3: Recycle all of e-waste fraction



Scenario 4: Recycle items that are easiest to recycle, landfill rest.



Scenario 5: Recycle most valuable and toxic waste streams and landfill the rest

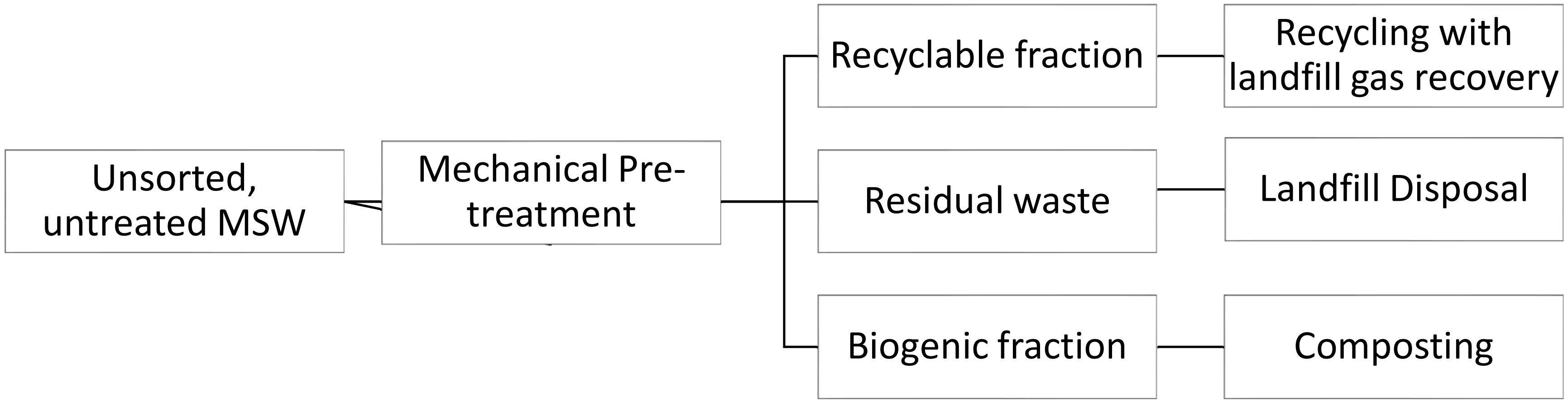


Figure A3: W.R.O.S.E Model (Trois & Kissoon, 2020)

Table A11: Gas emissions abbreviations (Abdelbasir, et al., 2018)

Abbreviation	ELCIA indicators as recommended by ILCD	Unit
GWP	Global warming potential	CO2-eq.
ODP	Ozone depletion potential	CFC-11-eq.
HumToxCan	Human toxicity cancer potential	CTUh
HumTox	Human toxicity non-toxic potential	CTUh
POCP	Photo-Oxidant creation potential	NMVOC-eq.
PM	Particulate matter	G
AP	Acidification potential	Mole of H+-eq.

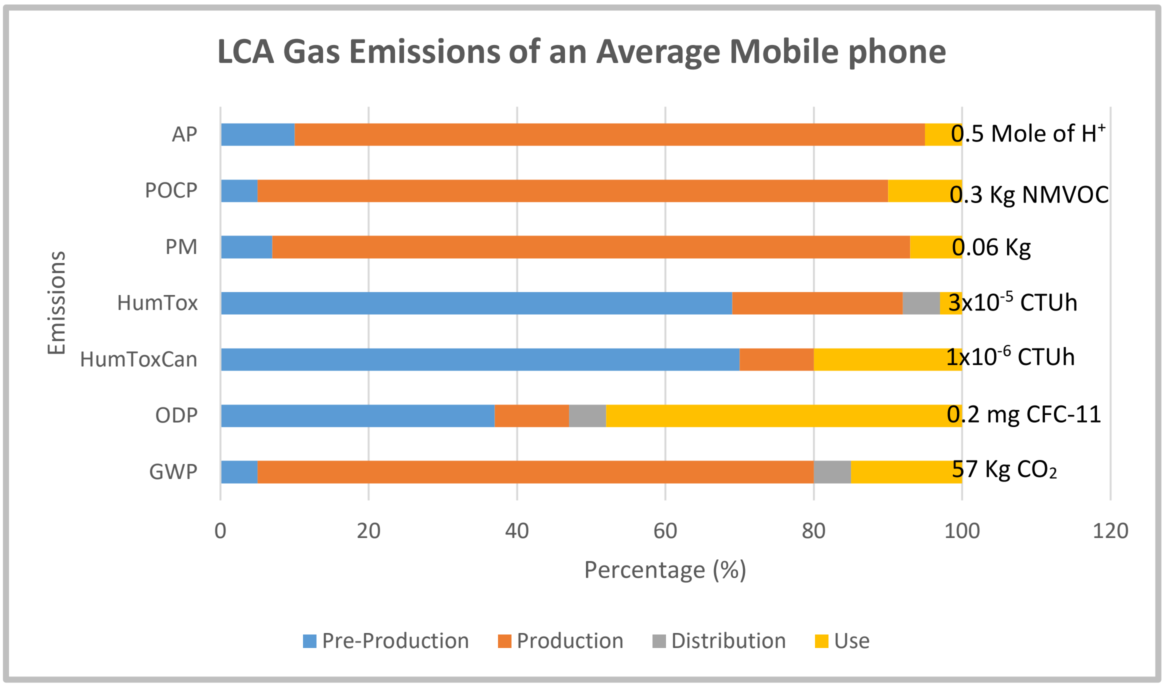


Figure A4: (Ercan, et al., 2016)

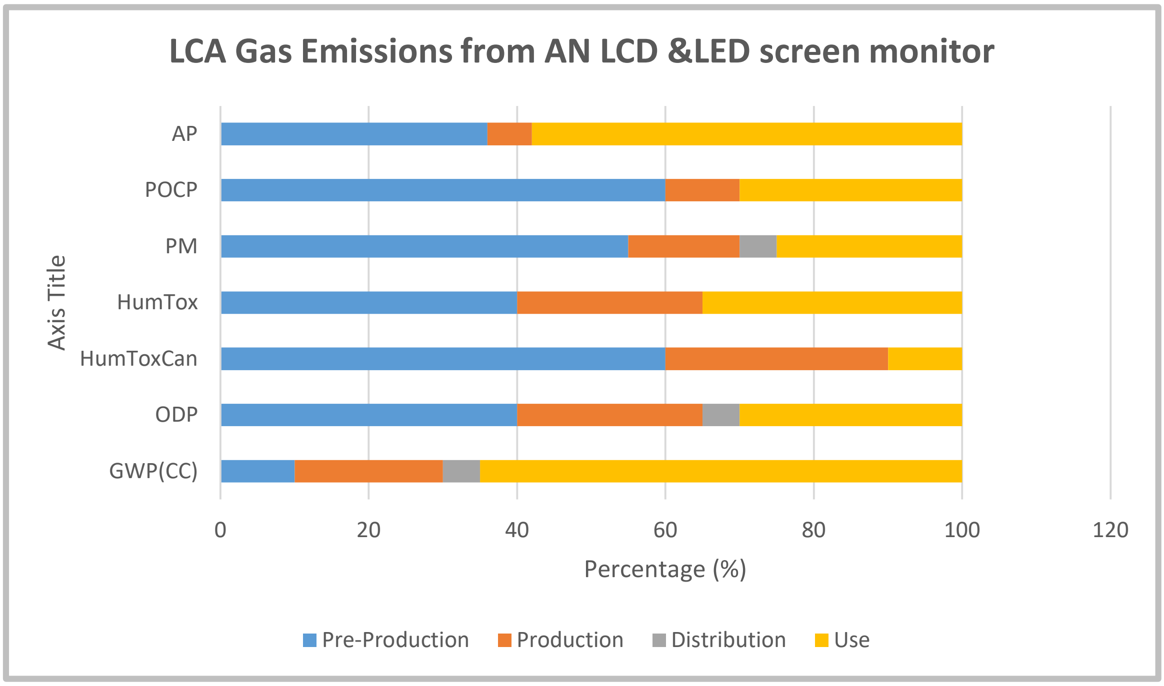


Figure A5: (Bhakar, et al., 2015)

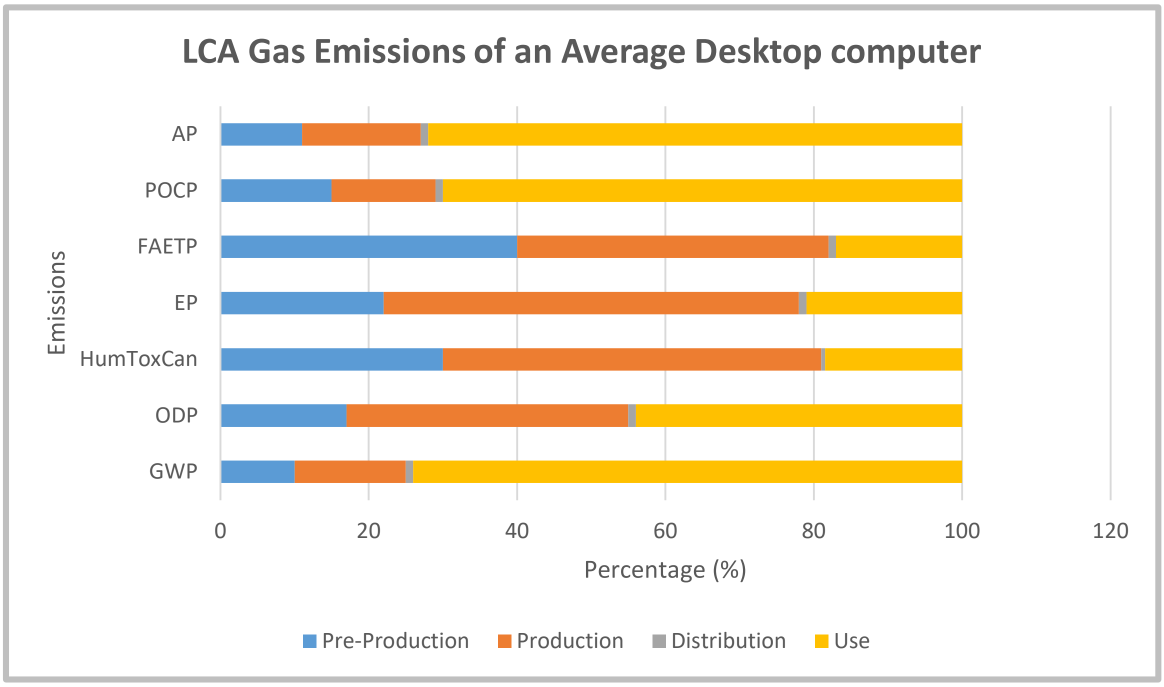


Figure A6: (Ercan, et al., 2016)

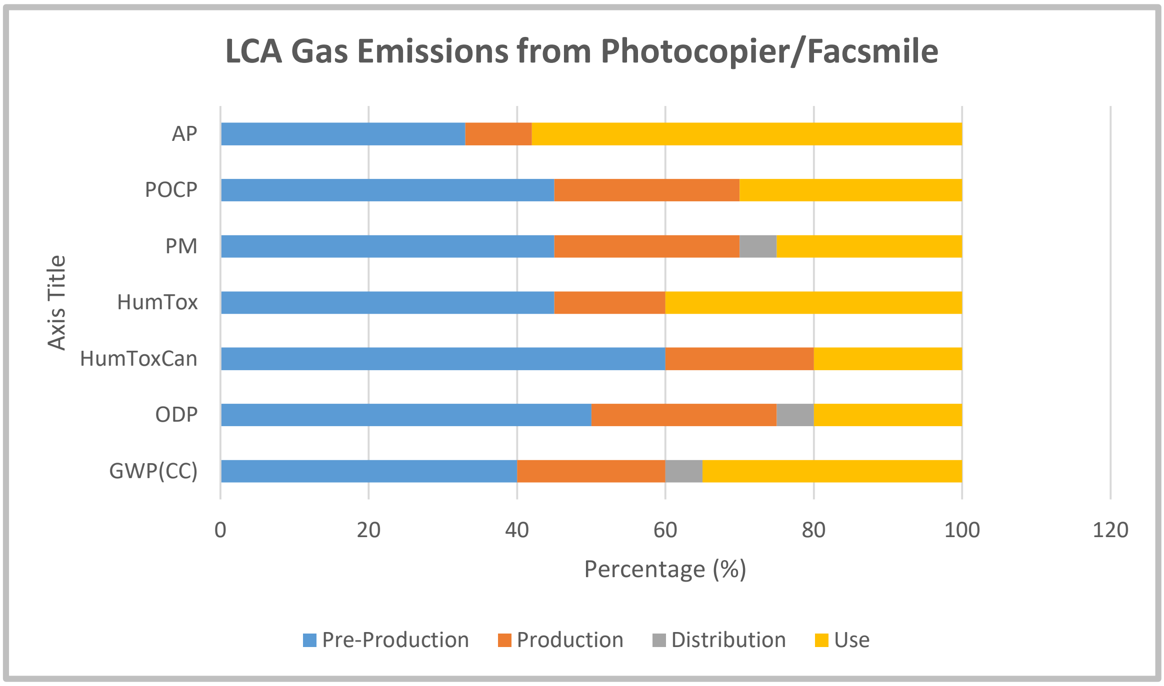


Figure A7: (Bhakar, et al., 2015)

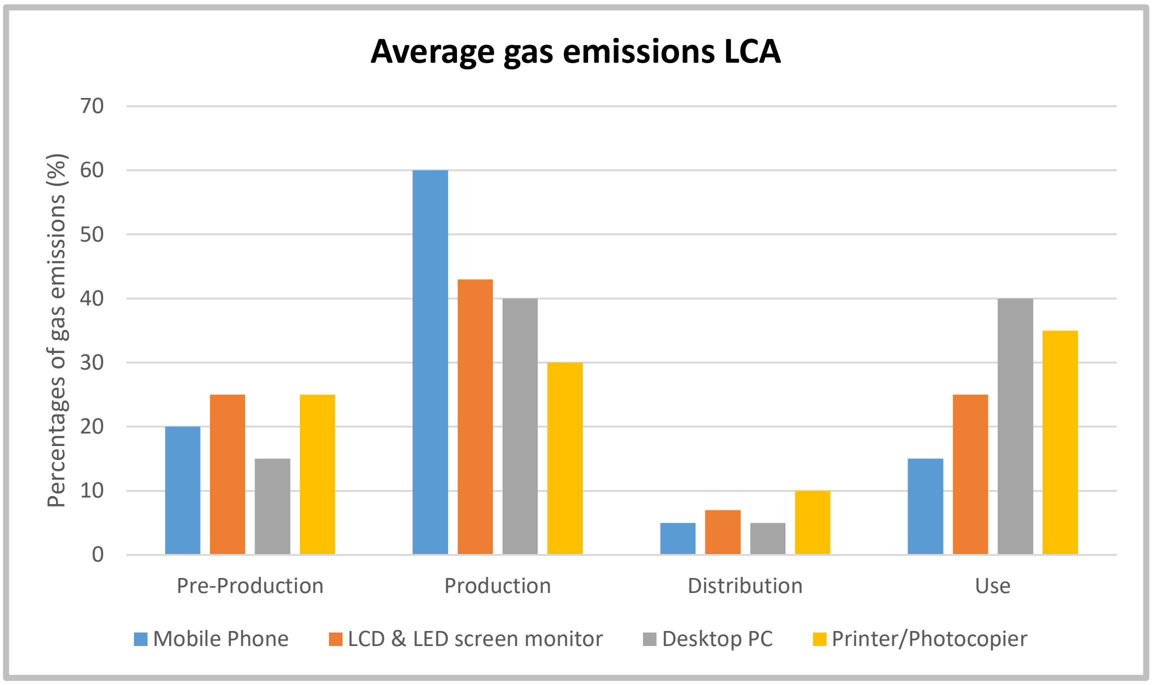


Figure A8: (Bhakar, et al., 2015; Ercan, et al., 2016)

Figure A9: SGD'S (TWI 2050, 2018)

Table A12: Select African countries that are signatories to the Basel Convention

Country	Date of enforcement
Algeria	14/12/1998
Botswana	18/08/1998
Burkina Faso	02/02/2000
Burundi	06/04/1997
Cameroon	10/05/2001
Central African Republic	25/05/2006
Chad	08/06/2004
Congo	19/07/2007
Côte d'Ivoire	01/03/1995
Democratic Republic of the Congo	04/01/1995
Djibouti	29/08/2002
Egypt	08/04/1993
Equatorial Guinea	08/05/2003
Eritrea	08/06/2005
Ethiopia	11/07/2000
Gabon	04/09/2008
Gambia	15/03/1998
Ghana	28/08/2003
Guinea	25/07/1995
Guinea-Bissau	10/05/2005
Kenya	30/08/2000
Lesotho	29/08/2000
Liberia	21/12/2004
Libya	10/10/2001
Madagascar	31/08/1999
Malawi	20/07/1994
Mauritania	14/11/1996
Mauritius	22/02/1993
Morocco	27/03/1996
Mozambique	11/06/1997
Namibia	13/08/1995
Niger	15/09/1998
Nigeria	05/05/1992
Rwanda	06/04/2004
Senegal	08/02/1993
Somalia	24/10/2010
South Africa	08/02/1993
Sudan	09/04/2006
Swaziland	06/11/2005
Togo	30/09/2004
Tunisia	09/01/1996
Uganda	09/06/1999
United Republic of Tanzania	06/07/1993
Zambia	13/02/1995
Zimbabwe	30/05/2012

Table A13: Summary of legislations

Legislation	Summary
Constitution	Deals with basic environmental rights. Sets out the allocation of powers for different levels of government. While provinces set the standards of environ-mental control within a national framework, local authorities are expected to administer the legislation, supplementing it with by-laws where necessary.
The National Environmental Management Act, 107 of 1998 (NEMA)	Amongst other things, NEMA lays out principles for waste management. These include avoidance or minimization, and the remediation of pollution. Waste reduction, re-use, recycling and proper disposal, as well as the 'polluter pays' and 'cradle to grave' principles are emphasized.
The Municipal Services Act, 32 of 2000	Includes principles for effective local governance.
The Occupational Health and Safety Act, 85 of 1993	Deals with health and safety in the workplace.
The Environment Conservation Act	Deals with the protection and controlled utilization of the environment. The Environment Conservation Act makes provision for an Environmental Impact Assessment (EIA) which is needed for any waste disposal activities. An amendment delegates the administration of waste disposal to DEAT. The permitting of waste disposal sites is guided by a series of documents dealing with minimum requirements.
The White Paper on Integrated Pollution and Waste Management (2000)	Deals with the allocation of environment and waste management functions and powers. Has also included the development of the National Waste Management Strategy, a joint venture between the DEAT and DWAF. The emphasis is on holistic waste and pollution management. The following waste management hierarchy is laid down for policy and legislative development: a) Waste avoidance, minimisation and prevention; b) recycling and reuse c) Treatment and handling d) Storage and final disposal. Recycling is one of the short-term priority areas identified.
The Health Act, 63 of 1977 and National Health Act, 61 of 2003	Promotes healthy living and working conditions. Relevant to the potential health risk implications of e-waste. Also deal with disposal of waste, and, amongst other health issues, the "accumulation of refuse…or other matter…

	injurious or dangerous to health" (Health Act, 63 of 1977, Section 1).
The Hazardous Substances Act	Regulates the management of hazardous substances and hazardous waste.
DWAF Minimum Requirements	In 1998 DWAF published detailed minimum requirements dealing with waste disposal by landfill, handling, classification and disposal of hazardous waste, water monitoring at waste management facilities. Also deals with storage of hazardous waste.
National Water Act, 36 of 1998	Act includes a reference to "Disposing of waste in a manner which may detrimentally impact on a water resource" (section 21(g)), which could have implications for e-waste management.
Atmospheric Pollution Prevention Act, 45 of 1965	Requires a registration certificate for certain processes, including lead, copper, waste incineration, cadmium, metal recovery, mercury, and glass processes.
Air Quality Act, 39 of 2004	This Act is only partially in force. It aims to improve air quality, although standards and control were still being formulated. Smelters, in particular, are likely to be affected. Once the licensing provisions enter into force they will replace the registration certificates currently issued in terms of the Atmospheric Pollution Prevention Act.
Hazardous Substances Act, 15 of 1973	Deals with the handling, selling, and use of hazardous substances.
Occupational Health and Safety Act, 85 of 1993, and Regulations	Regulates the health and safety of employees and the public in general. Amongst other things, employers are obliged to carry out risk and hazard assessments on a regular basis to determine any dangers posed by the work or materials used.
Precious Metals legislation	Legislation was considered in a state of flux. Governs gold, silver, platinum and other platinum group metals, namely palladium, rhodium, iridium, ruthenium and osmium.

Appendix B: Methodology

Appendix B1: Research questionnaire 1 (Survey of The University of Kwa-Zulu Natal)

(Adopted from K. Govender (2016))

Section A: Quantifying the amount of e-waste.

1. Number of desktop/laptop computers in your organisation (If unsure, estimate):			
		1. Currently in use.	2. Obsolete
A	Less than 5		
B	5-10		
C	11-30		
D	31-50		
E	51-80		
F	81-100		
G	More than 100		
H	No computers		

2. Total number of printers/photocopiers/scanners/ fax machines (If unsure, estimate):			
		1. Currently in use.	2. Obsolete
A	1		
B	2		
C	3		
D	4		
E	5		
F	More than 5		
G	No Printers		

3. Total number of air-conditioning units in your organisation (If unsure, estimate):			
		1. Currently in use.	2. Obsolete
A	Less than 5		
B	5-10		
C	11-15		
D	16-20		
E	21-25		
F	26-30		
G	More than 30		
H	No computers		

4. The total number of Projector in your Facility. If you are uncertain, please give an estimate.			
	Average	1. Currently in use.	2. Obsolete
A	1		
B	2		
C	3		
D	4		
E	5		
F	More than 5		
G	No Printers		

5. What is the main reason why electronic are disposed in your organisation?		
		Response
A	Broken or malfunctioning	
B	Obsolete hardware	
C	Obsolete software	
E	Other	

6. What is the condition of the electronics in your organisation, upon disposal? (Approximate)					
	Condition	PC	Printer	AC	Projector
A	Excellent				
B	Fairly good				
C	Moderate (Requires little refurbishment)				
D	Low requires new parts				
E	Waste				

7. How often are electronics upgraded, replaced or disposed in your organisation?		
	Average	Response
A	1-2 years	
B	3-4 years	
C	4-5 years	
D	6-7 years	
E	More than 7 years	

Section B: Management of e-waste

8. Does your organisation have a specified electronic waste management plan?		
A. Yes	B. No	C. Not sure

9. If No, how does your organisations manage electronic waste, either store or dispose of obsolete/redundant electronic waste?		
A. Store	B. Disposes	C. Not sure

10. If store, which of the following can be a reason for storing electronic waste?		
A	We are not aware of any authorised agent that will recycle our e-waste	
B	We have not yet given it thought	
C	We do not think we generate enough e-waste that needs disposal	
D	Other (specify)	

11. If dispose, how does your organisation dispose of its obsolete/redundant electronic and electrical equipment? (CMS)		
A	Treat it as ordinary office bin/municipal waste	
B	Dump it in specifically marked bins for Electronic Waste	
C	Dismantle and recycle it in-house	
D	Donate old electronic and electrical equipment	
E	Ask a recycling company to pick it up	
F	Supplier comes and takes it back	
G	Don't know	

12. To what extent do you agree or disagree with the statement that "there is limited information available on electronic waste management"				
A. Strongly disagree	B. Disagree	C. Neither disagree or agree	D. Agree	E. Strongly agree

13. To what extent do you agree or disagree with the statement that "it is important for organisations to have a strategy for the management of obsolete/redundant electronic and electrical equipment"?				
A. Strongly disagree	B. Disagree	C. Neither disagree or agree	D. Agree	E. Strongly agree

Section C: importance of e-waste recycling

14. Are you aware of any legislation that deals with the disposal of obsolete/redundant electronic and electrical equipment?		
A. Yes	B. No	C. Not sure

15. Are you aware of any environmental legislations regarding electronic waste?				
A. Strongly disagree	B. Disagree	C. Neither disagree nor agree	C. Agree	D. Strongly agree

16. To what extent do you agree or disagree with the statement that "obsolete/redundant electronic and electrical equipment contains harmful substances to the environment"?				
A. Strongly disagree	B. Disagree	C. Neither disagree nor agree	D. Agree	E. Strongly agree

17. Are you aware of the health risks associated with electronic waste?		
A. Yes	B. No	C. Not sure

18. To what extent do you agree or disagree with the statement that "obsolete/redundant electronic and electrical equipment contains no value"?				
A. Strongly disagree	B. Disagree	C. Neither disagree or agree	D. Agree	E. Strongly agree

19. Any other comments you wish to make or if you want a copy of the findings of the study, please provide the following contact details:		
Name of contact person	Telephone	E-mail

Appendix B2: Research questionnaire 2 (Survey of Electronic waste recyclers/resellers)

1.	**What does your organisation primarily do? (Select all that is applicable)**	
		Response
A	Recycle e-waste	
B	Refurbish e-waste	
C	Disposal of e-waste	
D	Resale of e-waste	
E	None of the above	

2.	**If your organisation recycles e-waste, what is the scale of operations (Select one that is most applicable)**	
		Response
A	Small (less than 500Kg's per day)	
B	Medium (1-2 tons per day)	
C	Large (4-5 tons per day)	
D	More than 5 tons	
E	None of the above	

3.	**What are the fixed cost of your operations (Select all that is applicable)**		
		Tick if applicable	Approximate monthly fee
A	Rent		
B	Equipment lease		

4.	**What are the Variable cost of your operations (Select all that is applicable)**		
		Tick if applicable	Approximate monthly fee
A	Labour		
B	Energy		
C	Materials		
D	Transport		

5.	**What are the approximate recycling recovery rates? (Approximate if necessary)**	
A	100 %	
B	90 %	
C	80 %	
D	70 %	

6. Does your organisation charge a customer fee?		
A. Yes	B. No	C. Not sure

7. If your organisation resells electronics, how much would you sell a desktop computer for in the following conditions? (HP 2000, as a reference)		
	Condition	Approximate
A	Excellent (fully functioning)	R
B	Fairly good (requires maintenance)	R
C	Moderate (Requires little refurbishment)	R
D	Low requires new parts	R
E	Waste	R

8. If your organisation resells electronics, how much would you sell a Printer for in the following conditions? (Xerox 2510 as a reference)		
	Condition	Approximate
A	Excellent (fully functioning)	R
B	Fairly good (requires maintenance)	R
C	Moderate (Requires little refurbishment)	R
D	Low requires new parts	R
E	Waste	R

9. If your organisation resale electronics, how much would you sell a Projector for in the following conditions? (Epson ST200, as a reference)		
	Condition	Approximate
A	Excellent (fully functioning)	R
B	Fairly good (requires maintenance)	R
C	Moderate (Requires little refurbishment)	R
D	Low requires new parts	R
E	Waste	R

10. If your organisation resale electronics, how much would you sell an Air conditioning unit for in the following conditions?(LG 2500, as a reference)		
	Condition	Approximate
A	Excellent (fully functioning)	R
B	Fairly good (requires maintenance)	R
C	Moderate (Requires little refurbishment)	R
D	Low requires new parts	R
E	Waste	R

Table B1: Sample size calculator (Sekaran and Bougie, 2014)

Required Sample Size†

Population Size	Confidence = 95%				Confidence = 99%			
	Margin of Error				Margin of Error			
	5.0%	3.5%	2.5%	1.0%	5.0%	3.5%	2.5%	1.0%
10	10	10	10	10	10	10	10	10
20	19	20	20	20	19	20	20	20
30	28	29	29	30	29	29	30	30
50	44	47	48	50	47	48	49	50
75	63	69	72	74	67	71	73	75
100	80	89	94	99	87	93	96	99
150	108	126	137	148	122	135	142	149
200	132	160	177	196	154	174	186	198
250	152	190	215	244	182	211	229	246
300	169	217	251	291	207	246	270	295
400	196	265	318	384	250	309	348	391
500	217	306	377	475	285	365	421	485
600	234	340	432	565	315	416	490	579
700	248	370	481	653	341	462	554	672
800	260	396	526	739	363	503	615	763
1,000	278	440	606	906	399	575	727	943
1,200	291	474	674	1067	427	636	827	1119
1,500	306	515	759	1297	460	712	959	1376
2,000	322	563	869	1655	498	808	1141	1785
2,500	333	597	952	1984	524	879	1288	2173
3,500	346	641	1068	2565	558	977	1510	2890
5,000	357	678	1176	3288	586	1066	1734	3842
7,500	365	710	1275	4211	610	1147	1960	5165
10,000	370	727	1332	4899	622	1193	2098	6239
25,000	378	760	1448	6939	646	1285	2399	9972
50,000	381	772	1491	8056	655	1318	2520	12455
75,000	382	776	1506	8514	658	1330	2563	13583
100,000	383	778	1513	8762	659	1336	2585	14227
250,000	384	782	1527	9248	662	1347	2626	15555
500,000	384	783	1532	9423	663	1350	2640	16055
1,000,000	384	783	1534	9512	663	1352	2647	16317
2,500,000	384	784	1536	9567	663	1353	2651	16478
10,000,000	384	784	1536	9594	663	1354	2653	16560
100,000,000	384	784	1537	9603	663	1354	2654	16584
300,000,000	384	784	1537	9603	663	1354	2654	16586

Appendix B3: Cover letter attached to research questionnaire.

Covering letter to the Questionnaire

Dear Sir/Madam

I am a registered Master's student in the "waste and resource management" programme, department of Engineering, University of Kwa-Zulu Natal. I am conducting a study on the management of Electronic waste, at UKZN Howard campus. In order to successfully complete my master dissertation, I need to conduct a questionnaire, and you have been identified as one of the respondents.

Your co-operation in assisting me with this important component of my study is highly appreciated, and I look forward to the completed questionnaire. Your permission is hereby requested to complete the questionnaire and return it to the researcher. This will be explained in the questionnaire that follows.

Rest assured that your responses will be treated with the utmost confidentiality and will not be divulged to any third party. On completion of this research project, if requested, a report on the findings will be e-mailed or posted to you.

Thank you for your time and cooperation.

Regards

Mayuren Govender

Tel: 084 319 1364

Email: 214513501@stu.ukzn.ac.za

Appendix C: Pilot study

C.1 Potential quantities

Lab Name	PC unit		Printers		Projectors		Air conditioning		Lab Manager
	online	Actual	online	Actual	online	Actual	online	Actual	
CIVIL_ENG-LAN	50	52	2		2	2	16	16	S. Olivier
CIVIL DESIGN STUDIO	20	28	0		0	0	2	2	S. Olivier
CIVIL POST GRAD	10	16	0		0	0	2	2	S. Olivier
Total	80	96	2	0	2	2	20	20	

Lecture venue Name	PC unit		Printers		Projectors		Air conditioning		Lab Manager
	online	Actual	online	Actual	online	Actual	online	Actual	
CENTENARY-G120	1	1	0	0	1	1	3	3	K.Dlamini
CENTENARY-G123	1	1	0	0	1	1	2	2	K.Dlamini
CENTENARY-G124	1	1	0	0	1	1	2	2	K.Dlamini
CENTENARY-220	1	1	0	0	1	1	3	3	K.Dlamini
CENTENARY-230	1	1	0	0	1	1	0	0	K.Dlamini
CENTENARY-G4	1	1	0	0	1	1	2	2	K.Dlamini
CENTENARY-G5	1	1	0	0	1	1	3	3	K.Dlamini
Total	7	7	0	0	7	7	15	15	K.Dlamini

Office Name	PC unit		Printers		Projectors		Air conditioning		Office Manager
	online	Actual	online	Actual	online	Actual	online	Actual	
Office 1	1	1	0	0	0	0	1	1	I. Ramikissoon
Office 2	0	0	0	0	0	0	1	1	I. Ramikissoon
Office 3	1	1	0	0	0	0	1	1	I. Ramikissoon
Office 4	1	1	0	0	0	0	0	0	I. Ramikissoon
Office 5	0	0	0	0	0	0	0	0	N.Kunene
Office 6	0	0	0	0	0	0	0	0	N.Kunene
Office 7	1	1	1	1	0	0	0	0	N.Kunene
Office 8	1	1	0	0	0	0	0	0	N.Kunene
Office 9	0	0	0	0	0	0	0	0	N.Kunene
Office 10	1	1	0	0	0	0	0	0	N.Kunene
TOTAL	6	6	1	1	0	0	3	3	N.Kunene

C.2. Susutainablity indicators

	Question		6	7	8	9	10	11	12	13	14	15	16	17
Catergory	Name													
CL	CIVIL_ENG-LAN		C	E	A	A	A	A	D	A	A	C	A	A
CL	CIVIL DESIGN STUDIO		C	E	A	A	A	A	D	A	A	C	A	A
CL	CIVIL POST GRAD		C	E	A	A	A	A	D	B	B	D	B	B
Office	Office 1		C	E	A	A	A	A	D	A	A	C	A	A
Office	Office 2		C	E	A	A	A	A	D	A	A	C	A	A
Office	Office 3		C	E	A	A	A	A	D	A	A	C	A	A
Office	Office 4		C	E	A	A	A	A	D	A	A	C	A	A
Office	Office 5		C	E	A	A	A	A	D	A	A	C	A	A
Office	Office 6		C	E	A	A	A	A	D	A	A	C	A	A
Office	Office 7		C	E	A	A	A	A	D	A	A	C	A	A
Office	Office 8		C	E	A	A	A	A	D	A	A	C	A	A
Office	Office 9		C	E	A	A	A	A	D	B	B	D	B	B
Office	Office 10		C	E	A	A	A	A	D	B	B	D	B	B
LV	CENTENARY-G120		C	E	A	A	A	A	D	A	A	C	A	A
LV	CENTENARY-G123		C	E	A	A	A	A	D	A	A	C	A	A
LV	CENTENARY-G124		C	E	A	A	A	A	D	A	A	C	A	A
LV	CENTENARY-220		C	E	A	A	A	A	D	A	A	C	A	A
LV	CENTENARY-230		C	E	A	A	A	A	D	A	A	C	A	A
LV	CENTENARY-G4		C	C	C	-	C	F	E	C	C	E	C	D
LV	CENTENARY-G5		C	C	C	-	C	F	E	C	C	E	C	D
		A			18	18	18	18		15	15		15	15
		B				0				3	3		3	3
		C	20	2	2		2			2	2	15	2	
		D							18			3		2
		E		18					2			2		
		F						2						
		G	20	20	20	18	20	20	20	20	20	20	20	20

	Question		6	7	8	9	10	11	12	13	14	15	16	17
Popular response (%)			**C**	**E**	**A**	**A**	**A**	**A**	**D**	**A**	**C**	**C**	**A**	**A**
	Computer Labaratory		100	100	100	100	100	100	100	66	66	66	66	66
	Offices		100	100	100	100	100	100	100	80	80	80	80	80
	Lecture venues		100	72	72	72	72	72	72	72	72	72	72	72

Appendix D: Results

D.1 Howard campus

D1.1. E-waste Volumes

Lan Name	**Question1:** Number of desktop/laptop computers in your organisation :							
	Less than 5	5-10	10-30	31-50	51-80	81-100	>100	None
ARCHI-LAN							1	
BLUE-LAN					1			
CIVIL_ENG-LAN					1			
CIVIL DESIGN STUDIO				1				
CIVIL POST GRAD			1					
COM_DEV		1						
DC_1						1		
DC_3					1			
DESIGN_STUDIO		1						
ELEC_ENG_2				1				
ELEC_ENG_3			1					
ENG_DC			1					
ENG_UNITE							1	
FISH_BOWL					1			
GREEN_LAN						1		
HOUSING_LAN					1			
ICS_TRAINING			1					
LAW_LIB				1				
LAW_PG			1					
LAW_RES				1				
LIB_LAN			1					
LIBGF_LAN			1					
LIBT LAN			1					
MLAW_LAN			1					
MULTIMEDIA_PG_				1				
MUSIC_LIBRARY			1					
NRF_LAN				1				
NURSING					1			
ORANGE			1					
PLANNING_LAN			1					
PURPLE_LAN				1				
RED_LAN			1					
SARCHI			1					
SARCHI_PHD_LAB			1					
SARCHI-POVERTY	1							
SEMINAR ROOM		1						
SHEP_9				1				
SHEP_9 ANNEX			1					
SOBED-TUTORS	1							
SUPERBOWL					1			
UMF		1						
VENTER							1	
Total responses	2	4	16	8	7	2	3	0
Mean	2.5		20	40.5	65.5	90.5	100	
Total units	5	0	320	324	458.5	181	300	
								1588.5

Lan Name	**Question 2:** Total number of printers/photocopiers/scanners/ fax machines:							
	1	2	3	4	5	>5	None	
ARCHI-LAN		1						
BLUE-LAN	1							
CIVIL_ENG-LAN		1						
CIVIL DESIGN STUDIO							1	
CIVIL POST GRAD							1	
COM_DEV							1	
DC_1		1						
DC_3			1					
DESIGN_STUDIO	1							
ELEC_ENG_2		1						
ELEC_ENG_3	1							
ENG_DC							1	
ENG_UNITE			1					
FISH_BOWL		1						
GREEN_LAN							1	
HOUSING_LAN	1							
ICS_TRAINING	1							
LAW_LIB	0					1		
LAW_PG						1		
LAW_RES		1						
LIB_LAN		1						
LIBGF_LAN						1		
LIBT LAN							1	
MLAW_LAN		1						
MULTIMEDIA_PG_							1	
MUSIC_LIBRARY						1		
NRF_LAN	1							
NURSING		1						
ORANGE	1							
PLANNING_LAN							1	
PURPLE_LAN	1							
RED_LAN							1	
SARCHI	1							
SARCHI_PHD_LAB	1							
SARCHI-POVERTY							1	
SEMINAR ROOM							1	
SHEP_9	1							
SHEP_9 ANNEX	1							
SOBED-TUTORS	1							
SUPERBOWL		1						
UMF							1	
VENTER		1						
Total responses	13	11	2	0	0	4	12	
Mean	1	2	3	4	5	7.5	0	
Total units	13	22	6	0	0	30	0	
								120

Lan Name	**Question 3:** Total number of computer screens/security monitors/televisions							
	Less than 5	5-10	11-15	16-20	21-25	26-30	30>	None
ARCHI-LAN							1	
BLUE-LAN					1			
CIVIL_ENG-LAN					1			
CIVIL DESIGN STUDIO				1				
CIVIL POST GRAD			1					
COM_DEV		1						
DC_1						1		
DC_3					1			
DESIGN_STUDIO		1						
ELEC_ENG_2				1				
ELEC_ENG_3			1					
ENG_DC			1					
ENG_UNITE							1	
FISH_BOWL					1			
GREEN_LAN						1		
HOUSING_LAN					1			
ICS_TRAINING			1					
LAW_LIB				1				
LAW_PG			1					
LAW_RES				1				
LIB_LAN			1					
LIBGF_LAN			1					
LIBT LAN			1					
MLAW_LAN			1					
MULTIMEDIA_PG_				1				
MUSIC_LIBRARY			1					
NRF_LAN				1				
NURSING					1			
ORANGE			1					
PLANNING_LAN			1					
PURPLE_LAN				1				
RED_LAN			1					
SARCHI			1					
SARCHI_PHD_LAB			1					
SARCHI-POVERTY								
SEMINAR ROOM		1						
SHEP_9				1				
SHEP_9 ANNEX			1					
SOBED-TUTORS								
SUPERBOWL					1			
UMF		1						
VENTER							1	
Total responses	0	4	16	8	7	2	3	0
Mean	0	7.5	13	18	23	28	30	0
Total units	0	30	208	144	161	56	90	0

	Question 4: Total number of air-conditioning units in your organisation								Question 5: The total number of Projector in your Facility						
Lan Name	Less than 5	5-10	11-15	16-20	21-25	26-30	30>	None	1	2	3	4	5	>5	None
ARCHI-LAN	0														1
BLUE-LAN		1							1						
CIVIL_ENG-LAN				1					1						
CIVIL DESIGN STUDIO	1														1
CIVIL POST GRAD	1														1
COM_DEV								1							1
DC_1		1							1						
DC_3		1							1						
DESIGN_STUDIO								1							1
ELEC_ENG_2	1								1						
ELEC_ENG_3	1														1
ENG_DC	1														1
ENG_UNITE		1								1					
FISH_BOWL								1							1
GREEN_LAN		1							1						
HOUSING_LAN	1								1						
ICS_TRAINING	1								1						
LAW_LIB		1							1						
LAW_PG	1								1						
LAW_RES								1							1
LIB_LAN		1							1						
LIBGF_LAN		1							1						
LIBT LAN		1													1
MLAW_LAN	1														1
MULTIMEDIA_PG_								1	1						
MUSIC_LIBRARY	1														1
NRF_LAN															1
NURSING										1					
ORANGE									1						
PLANNING_LAN															1
PURPLE_LAN															1
RED_LAN															1
SARCHI															1
SARCHI_PHD_LAB															1
SARCHI-POVERTY															1
SEMINAR ROOM									1						
SHEP_9									1						
SHEP_9 ANNEX									1						
SOBED-TUTORS															1
SUPERBOWL															1
UMF															1
VENTER										1					
Total responses	10	9	0	1	0	0	0	5	17	3	0	0	0	0	22
Mean	5	7.5	13	18	23	28	30	0	1	2	3	4	5	7.5	0
Total units	50	67.5	0	18	0	0	0	0	17	6	0	0	0	0	0
								135.5							23

D.1.2 Sustainability indicators

Question		6	7	8	9	10	11	12	13	14	15	16	17
Lan Name													
ARCHI-LAN		C	E	A	A	A	A	D	A	A	C	A	A
BLUE-LAN		C	E	A	A	A	A	D	A	A	C	A	A
CIVIL_ENG-LAN		C	E	A	A	A	A	D	A	A	C	A	A
CIVIL DESIGN STUDIO		C	E	A	A	A	A	D	A	A	C	A	A
CIVIL POST GRAD		C	E	A	A	A	A	D	A	A	C	A	A
COM_DEV		C	E	A	A	A	A	D	A	A	C	A	A
DC_1		C	E	A	A	A	A	D	B	A	C	A	A
DC_3		C	E	A	A	A	A	D	B	A	C	A	A
DESIGN_STUDIO		C	E	A	A	A	A	D	B	A	C	A	A
ELEC_ENG_2		C	E	A	A	A	A	D	B	A	C	A	A
ELEC_ENG_3		C	E	A	A	A	A	D	B	A	C	B	B
ENG_DC		C	E	A	A	A	A	D	B	A	C	B	B
ENG_UNITE		C	E	A	A	A	A	D	B	A	D	B	B
FISH_BOWL		C	E	A	A	A	A	D	B	A	D	B	B
GREEN_LAN		C	E	A	A	A	A	D	B	B	D	B	B
HOUSING_LAN		C	E	B	-	A	A	D	B	B	D	B	B
ICS_TRAINING		C	D	B	-	A	A	D	B	B	D	B	B
LAW_LIB		C	D	B	-	A	A	D	B	B	D	B	B
LAW_PG		C	D	B	-	A	A	D	B	B	D	B	B
LAW_RES		C	D	B	-	A	A	D	C	B	D	B	B
LIB_LAN		C	D	B	-	A	A	D	C	B	D	B	B
LIBGF_LAN		C	D	B	-	A	A	D	C	B	D	B	B
LIBT LAN		C	D	B	-	B	D	D	C	B	D	B	B
MLAW_LAN		C	D	B	-	B	D	D	C	B	D	B	B
MULTIMEDIA_PG_		C	D	B	-	B	D	D	C	B	D	B	B
MUSIC_LIBRARY		C	D	B	-	B	D	D	C	B	D	B	C
NRF_LAN		C	D	C	-	B	D	D	C	B	D	B	C
NURSING		C	D	C	-	B	D	E	C	B	E	B	C
ORANGE		C	D	C	-	B	D	E	C	B	E	B	C
PLANNING_LAN		C	D	C	-	B	D	E	C	C	E	B	C
PURPLE_LAN		C	D	C	-	C	D	E	C	C	E	C	C
RED_LAN		C	D	C	-	C	D	E	C	C	E	C	C
SARCHI		C	D	C	-	C	D	E	C	C	E	C	C
SARCHI_PHD_LAB		C	C	C	-	C	D	E	C	C	E	C	D
SARCHI-POVERTY		C	C	C	-	C	E	E	C	C	E	C	D
SEMINAR ROOM		C	C	C	-	C	E	E	C	C	E	C	D
SHEP_9		C	C	C	-	C	E	E	C	C	E	C	D
SHEP_9 ANNEX		C	C	C	-	C	E	E	C	C	E	C	D
SOBED-TUTORS		C	C	C	-	C	F	E	C	C	E	C	D
SUPERBOWL		C	C	C	-	C	F	E	C	C	E	C	D
UMF		C	C	C	-	C	F	E	C	C	E	C	D
VENTER		C	C	C	-	C	F	E	C	C	E	C	D
Responses													
A		-	-	15	15	22	21	30	6	15	-	10	10
B		-	-	11	-	9	-	12	15	17	-	20	17
C		42	9	16	-	11	-	-	21	10	12	12	10
D		-	17	-	-	-	13	-	-	-	15	-	5
E		-	17	-	-	-	4	-	-	-	15	-	-
F		-	-	-	-	-	4	-	-	-	-	-	-

D.2 Westville campus

D.2.1. E-waste Volumes

		Question1: Number of desktop/laptop computers in your organisation :									**Question 2**:Total number of printers/photocopiers/scanners/ fax machines:									**Question 3**:Total number of computer screens/security monitors/televisions							
Lan Name		Less than 5	5-10	10-30	31-50	51-80	81-100	>100	None		1	2	3	4	5	>5	None			Less than 5	5-10	11-15	16-20	21-25	26-30	30>	None
ANATOMY		1									1																
BIO-LAN								1					1														
DSU				1													1										
ECONOMICS			1														1										
GREEN-WESTVILLE								1						1													
GSB-LAN					1						1																
HISTOLOGY						1					1																
ICS_GREY_LAN						1					1																
IS&T-ANT						1					1																
IS&T-BLUE							1					1															
IS&T-G20						1						1															
IS&T-RED						1						1															
POSTGRAD_HEALTH SCIENCE				1													1										
POSTGRAD_LAN					1												1										
WST_LIBRARY					1							1															
WST_RESEARCH_COMMONS					1																						
Total responses		1	1	2	4	5	1	2	0		5	4	1	1	0	0	4			0	0	0	0	0	0	0	0
Mean		2.5		20	40.5	65.5	90.5	100			1	2	3	4	5	7.5	0			0	7.5	13	18	23	28	30	0
Total units		2.5	0	40	162	327.5	90.5	200			5	8	3	4	0	0	0			0	0	0	0	0	0	0	0

		Question 4: Total number of air-conditioning units in your organisation									**Question 5:** The total number of Projector in your Facility						
Lan Name		Less than 5	5-10	11-15	16-20	21-25	26-30	30>	None		1	2	3	4	5	>5	None
ANATOMY		1															1
BIO-LAN			1									1					
DSU									1								1
ECONOMICS									1								1
GREEN-WESTVILLE			1									1					
GSB-LAN									1								1
HISTOLOGY		1									1						
ICS_GREY_LAN		1									1						
IS&T-ANT		1									1						
IS&T-BLUE		1									1						
IS&T-G20			1														1
IS&T-RED			1														1
POSTGRAD_HEALTH SCIENCE									1								1
POSTGRAD_LAN									1								1
WST_LIBRARY									1		1						
WST_RESEARCH_COMMONS									1								1
Total responses		5	4	0	0	0	0	0	7		5	2	0	0	0	0	9
Mean		5	7.5	13	18	23	28	30	0		1	2	3	4	5	7.5	0
Total units		25	30	0	0	0	0	0	55		5	4	0	0	0	0	9

D.2.2 Sustainability indicators

Question		6	7	8	9	10	11	12	13	14	15	16	17
Lan Name													
ANATOMY		C	C	A	A	A	A	D	A	A	C	A	A
BIO-LAN		C	C	A	A	A	A	D	A	A	C	A	A
DSU		C	C	A	A	A	A	D	A	A	C	A	A
ECONOMICS		C	C	A	A	A	A	D	B	A	C	A	B
GREEN-WESTVILLE		C	D	A	A	A	A	D	B	B	D	A	B
GSB-LAN		C	D	A	A	A	A	D	B	B	D	A	B
HISTOLOGY		C	D	A	A	A	A	D	B	B	D	B	B
ICS_GREY_LAN		C	D	B	-	A	A	D	B	B	D	B	B
IS&T-ANT		C	D	B	-	B	D	D	C	B	D	B	B
IS&T-BLUE		C	D	B	-	B	D	D	C	B	D	B	B
IS&T-G20		C	E	B	-	B	E	E	C	B	E	B	C
IS&T-RED		C	E	C	-	B	E	E	C	B	E	B	C
POSTGRAD_HEALTH SCIENCE		C	E	C	-	C	F	E	C	C	E	B	C
POSTGRAD_LAN		C	E	C	-	C	F	E	C	C	E	B	C
WST_LIBRARY		C	E	C	-	C	D	E	C	C	E	C	C
WST_RESEARCH_COMMONS		C	E	C	-	C	D	E	C	C	E	C	C
Responses													
A		-	-	7	7	8	8	-	3	4	-	6	3
B		-	-	4	-	4	-	-	5	8	-	8	7
C		16	4	5	-	4	-	-	9	4	4	2	6
D		-	6	-	-	-	4	10	-	-	6	-	-
E		-	6	-	-	-	2	6	-	-	6	-	-
F		-	-	-	-	-	2	-	-	-	-	-	-

D.3 Medical School campus

D.3.1. E-waste Volumes

Lan Name	**Question1:** Number of desktop/laptop computers in your organisation :							
	Less than 5	5-10	10-30	31-50	51-80	81-100	>100	None
MEDICAL SCHOOL LAN_A							1	
MEDICAL SCHOOL LAN_B					1			
MEDICAL SCHOOL PG_LAN				1				
Total responses	0	0	0	1	1	0	1	0
Mean	2.5		20	40.5	65.5	90.5	100	
Total units	0	0	0	40.5	65.5	0	100	206

Lan Name	**Question 2:** Total number of printers/photocopiers/scanners/ fax machines:							
	1	2	3	4	5	>5	None	
MEDICAL SCHOOL LAN_A				1				
MEDICAL SCHOOL LAN_B		1						
MEDICAL SCHOOL PG_LAN		1						
Total responses	0	2	0	1	0	0	0	
Mean	1	2	3	4	5	7.5	0	
Total units	0	4	0	4	0	0	0	8

Lan Name	**Question 3:** Total number of computer screens/security monitors/televisions							
	Less than 5	5-10	11-15	16-20	21-25	26-30	30>	None
MEDICAL SCHOOL LAN_A							1	
MEDICAL SCHOOL LAN_B					1			
MEDICAL SCHOOL PG_LAN					1			
Total responses	0	0	0	0	2	0	1	0
Mean	0	7.5	13	18	23	28	30	0
Total units	0	0	0	0	46	0	30	76

Lan Name	**Question 4:** Total number of air-conditioning units in your organisation							
	Less than 5	5-10	11-15	16-20	21-25	26-30	30>	None
MEDICAL SCHOOL LAN_A			1					
MEDICAL SCHOOL LAN_B		1						
MEDICAL SCHOOL PG_LAN		1						
Total responses	0	2	1	0	0	0	0	0
Mean	5	7.5	13	18	23	28	30	0
Total units	0	15	13	0	0	0	0	28

Lan Name	**Question 5:** The total number of Projector in your Facility						
	1	2	3	4	5	>5	None
MEDICAL SCHOOL LAN_A							1
MEDICAL SCHOOL LAN_B	1						
MEDICAL SCHOOL PG_LAN	1						
Total responses	2	0	0	0	0	0	1
Mean	1	2	3	4	5	7.5	0
Total units	2	0	0	0	0	0	0

D.3.2. Sustainability indicators

Question		6	7	8	9	10	11	12	13	14	15	16	17
Lan Name													
MEDICAL SCHOOL LAN_A		C	E	A	A	A	A	D	B	A	D	B	B
MEDICAL SCHOOL LAN_B		C	E	A	A	A	A	D	C	B	D	B	B
MEDICAL SCHOOL PG_LAN		C	D	C	-	B	D	E	C	B	E	B	B
Responses													
A		-	-	2	2	2	2	-	-	1	-	-	-
B		-	-	-	-	-	-	-	1	2	-	3	3
C		3	-	1	-	-	-	-	2	-	-	-	-
D		-	1	-	-	1	1	2	-	-	2	-	-
E		-	2	-	-	-	-	1	-	-	1	-	-
F		-	-	-	-	-	-	-	-	-	-	-	-

D.4 PMB campus

D.4.1. E-waste Volumes

		Question1: Number of desktop/laptop computers in your organisation :									**Question 2**:Total number of printers/photocopiers/scanners/ fax machines:							
Lan Name		Less than 5	5-10	10-30	31-50	51-80	81-100	>100	None		1	2	3	4	5	>5	None	
AGRIC_341					1						1							
AGRIC_343				1													1	
AGRIC_PHD			1														1	
ARTS_227_PMB					1						1							
ARTS_232_PMB				1													1	
ARTS_236_PMB					1												1	
COMMERCE_C9					1						1							
G20_LAN						1						1						
G45_PMB					1												1	
G46_PMB					1						1							
G47_PMB					1						1							
GREYS_HOSPITAL_LAN			1														1	
JOHN_BEWS-PMB					1							1						
LANGUAGE-LAB			1														1	
LIBRARY_ISSUE_DESK				1													1	
LIFE_SCIENCE_LIBRARY			1														1	
MALHERBE						1						1						
MED_LAN A				1													1	
NEW_ARTS_220				1													1	
PGD_CENTRE LAN				1													1	
PMB-DSU					1												1	
PMB_RC				1													1	
SCI_PGD				1													1	
Total responses		0	4	8	9	2	0	0	0		5	3	0	0	0	0	15	
Mean		2.5		20	40.5	65.5	90.5	100			1	2	3	4	5	7.5	0	
Total units		0	0	160	364.5	131	0	0	655.5		5	6	0	0	0	0	0	11

Lan Name	**Question 3:** Total number of computer screens/security monitors/televisions							
	Less than 5	5-10	11-15	16-20	21-25	26-30	30>	None
AGRIC_341		1						
AGRIC_343								
AGRIC_PHD								
ARTS_227_PMB		1						
ARTS_232_PMB								
ARTS_236_PMB								
COMMERCE_C9		1						
G20_LAN			1					
G45_PMB								
G46_PMB		1						
G47_PMB		1						
GREYS_HOSPITAL_LAN					1			
JOHN_BEWS-PMB			1					
LANGUAGE-LAB								
LIBRARY_ISSUE_DESK								
LIFE_SCIENCE_LIBRARY								
MALHERBE			1					
MED_LAN A								
NEW_ARTS_220				1				
PGD_CENTRE LAN								
PMB-DSU								
PMB_RC								
SCI_PGD								
Total responses	0	5	3	1	1	0	0	0
Mean	0	7.5	13	18	23	28	30	0
Total units	0	37.5	39	18	23	0	0	0

Lan Name	**Question 4:** Total number of air-conditioning units in your organisation							
	Less than 5	5-10	11-15	16-20	21-25	26-30	30>	None
AGRIC_341	1							
AGRIC_343								1
AGRIC_PHD								1
ARTS_227_PMB	1							
ARTS_232_PMB								1
ARTS_236_PMB								1
COMMERCE_C9	1							
G20_LAN		1						
G45_PMB								1
G46_PMB								1
G47_PMB	1							
GREYS_HOSPITAL_LAN								1
JOHN_BEWS-PMB	1							
LANGUAGE-LAB								1
LIBRARY_ISSUE_DESK								1
LIFE_SCIENCE_LIBRARY								1
MALHERBE		1						
MED_LAN A								1
NEW_ARTS_220	1							
PGD_CENTRE LAN								1
PMB-DSU	1							
PMB_RC								1
SCI_PGD								1
Total responses	7	2	0	0	0	0	0	14
Mean	5	7.5	13	18	23	28	30	0
Total units	35	15	0	0	0	0	0	50

Lan Name	**Question 5:** The total number of Projector in your Facility						
	1	2	3	4	5	>5	None
AGRIC_341	1						
AGRIC_343							1
AGRIC_PHD							1
ARTS_227_PMB	1						
ARTS_232_PMB							1
ARTS_236_PMB	1						
COMMERCE_C9	1						
G20_LAN		1					
G45_PMB							1
G46_PMB							1
G47_PMB	1						
GREYS_HOSPITAL_LAN							1
JOHN_BEWS-PMB	1						
LANGUAGE-LAB							1
LIBRARY_ISSUE_DESK							1
LIFE_SCIENCE_LIBRARY							1
MALHERBE		1					
MED_LAN A							1
NEW_ARTS_220	1						
PGD_CENTRE LAN	1						
PMB-DSU							1
PMB_RC							1
SCI_PGD							1
Total responses	8	2	0	0	0	0	13
Mean	1	2	3	4	5	7.5	0
Total units	8	4	0	0	0	0	0

D.4.2. Sustainability indicators

Question		6	7	8	9	10	11	12	13	14	15	16	17
Lan Name													
AGRIC_341		C	C	A	A	A	A	D	A	A	C	A	A
AGRIC_343		C	C	A	A	A	A	D	A	A	C	A	A
AGRIC_PHD		C	C	A	A	A	A	D	A	A	C	A	A
ARTS_227_PMB		C	C	A	A	A	A	D	A	A	C	A	A
ARTS_232_PMB		C	C	A	A	A	A	D	A	A	C	A	A
ARTS_236_PMB		C	D	A	A	A	A	D	B	A	D	A	A
COMMERCE_C9		C	D	A	A	A	A	D	B	A	D	A	A
G20_LAN		C	D	A	A	A	A	D	B	B	D	B	A
G45_PMB		C	D	A	A	A	A	D	B	B	D	B	A
G46_PMB		C	D	B	-	A	A	D	B	B	D	B	A
G47_PMB		C	D	B	-	A	A	D	B	B	D	B	A
GREYS_HOSPITAL_LAN		C	D	B	-	A	A	D	B	B	D	B	B
JOHN_BEWS-PMB		C	D	B	-	B	A	D	B	B	D	B	B
LANGUAGE-LAB		C	D	C	-	B	D	D	C	B	D	B	B
LIBRARY_ISSUE_DESK		C	E	C	-	B	D	E	C	B	E	B	B
LIFE_SCIENCE_LIBRARY		C	E	C	-	B	D	E	C	B	E	B	B
MALHERBE		C	E	C	-	C	D	E	C	B	E	B	B
MED_LAN A		C	E	C	-	C	D	E	C	C	E	B	B
NEW_ARTS_220		C	E	C	-	C	E	E	C	C	E	C	B
PGD_CENTRE LAN		C	E	C	-	C	E	E	C	C	E	C	B
PMB-DSU		C	E	C	-	C	E	E	C	C	E	C	B
PMB_RC		C	E	C	-	C	F	E	C	C	E	C	B
SCI_PGD		C	E	C	-	C	F	E	C	C	E	C	B
Responses													
A		-	-	9	9	12	13	-	5	6	-	7	11
B		-	-	4	-	4	-	-	8	11	-	11	12
C		23	5	10	-	7	-	-	10	6	5	5	
D		-	9	-	-	-	5	14	-	-	9		
E		-	9	-	-	-	3	9	-	-	9		
F		-	-	-	-	-	2	-	-	-	-		

D.5 Edgewood campus

D.5.1. E-waste Volumes

	Question1: Number of desktop/laptop computers in your organisation :								**Question 2**:Total number of printers/photocopiers/scanners/ fax machines:							
Lan Name	Less than 5	5-10	10-30	31-50	51-80	81-100	>100	None	1	2	3	4	5	>5	None	
			1												1	
D_S_U					1					1						
EDG_ORANGE			1												1	
EDG-RED_LAN			1						1							
EDGEWOOD RESEARCH COMMONS	1														1	
EGM_RESEARCH_COMMONS					1				1							
LAN_2			1						1							
LAN_3			1												1	
LAN_4					1				1							
LAN_5					1					1						
LAN_6				1					1							
MEDIA_LAN	1	0	5	1	4	0	0	0	5	2	0	0	0	0	4	
Mean	2.5		20	40.5	65.5	90.5	100		1	2	3	4	5	7.5	0	
Total units	2.5	0	100	40.5	262	0	0	405	5	4	0	0	0	0	0	9

		Question 3: Total number of computer screens/security monitors/televisions									**Question 4:** Total number of air-conditioning units in your organisation									**Question 5:** The total number of Projector in your Facility						
Lan Name		Less than 5	5-10	11-15	16-20	21-25	26-30	30>	None		Less than 5	5-10	11-15	16-20	21-25	26-30	30>	None		1	2	3	4	5	>5	None
																		1								1
D_S_U												1								1						
EDG_ORANGE											1									1						
EDG-RED_LAN											1									1						
EDGEWOOD RESEARCH COMMONS																		1								1
EGM_RESEARCH_COMMONS												1								1						
LAN_2																		1								1
LAN_3											1									1						
LAN_4											1									1						
LAN_5											1									1						
LAN_6											1															1
MEDIA_LAN		0	0	0	0	0	0	0	0		6	2	0	0	0	0	0	3		7	0	0	0	0	0	4
Mean		0	7.5	13	18	23	28	30	0		5	7.5	13	18	23	28	30	0		1	2	3	4	5	7.5	0
Total units		0	0	0	0	0	0	0	0		30	15	0	0	0	0	0	45		7	0	0	0	0	0	0

D.5.2. Sustainability indicators

Question		6	7	8	9	10	11	12	13	14	15	16	17
Lan Name													
D_S_U		C	C	A	A	A	A	D	A	A	C	A	A
EDG_ORANGE		C	C	A	A	A	A	D	B	A	C	A	A
EDG-RED_LAN		C	D	A	A	A	A	D	B	B	D	A	A
EDGEWOOD RESEARCH COMMONS		C	D	A	A	A	A	D	C	B	D	B	A
EGM_RESEARCH_COMMONS		C	D	A	A	A	A	D	C	B	D	B	B
LAN_2		C	D	B	-	B	A	D	C	B	D	B	A
LAN_3		C	E	B	-	B	D	D	C	B	E	B	B
LAN_4		C	E	B	-	B	D	E	C	C	E	B	B
LAN_5		C	E	C	-	C	D	E	C	C	E	B	B
LAN_6		C	E	C	-	C	E	E	C	C	E	C	B
MEDIA_LAN		C	E	C	-	C	F	E	C	C	E	C	B
Responses													
A				5	5	5	6	-	1	2	-	3	5
B				3	-	3	-	-	2	5	-	7	6
C		11	2	3	-	3	-	-	7	4	2	2	
D			4	-	-	-	3	7	-	-	4		
E			5	-	-	-	1	4	-	-	5		
F				-	-	-	1	-	-	-	-		

Appendix E: IWMP

APPENDIX E1 : Summary of quantities of waste

	CATEGORY	Total units	Wieght per unit(KG)	Total wieght (KG)	waste per year (KG)
HOWARD	PC	1589	14.5	23033.25	4606.65
	Printers	120	34.5	4140	828
	Projectors	23	3.6	82.8	16.56
	Air conditioners	136	26	3523	704.6
				Sub-Total	6155.81
PMB	PC	656	14.5	9512	1902.4
	Printers	11	34.5	379.5	75.9
	Projectors	4	3.6	14.4	2.88
	Air conditioners	50	26	1300	260
				Sub-Total	2241.18
UDW	PC	823	14.5	11933.5	2386.7
	Printers	20	34.5	690	138
	Projectors	9	3.6	32.4	6.48
	Air conditioners	55	26	1430	286
				Sub-Total	2817.18
EW	PC	405	14.5	5872.5	1174.5
	Printers	9	34.5	310.5	62.1
	Projectors	7	3.6	25.2	5.04
	Air conditioners	45	26	1170	234
				Sub-Total	1475.64
MDS	PC	206	14.5	2987	597.4
	Printers	8	34.5	276	55.2
	Projectors	4	3.6	14.4	2.88
	Air conditioners	28	26	728	145.6
				Sub-Total	801.08
			Total	67454.45	13490.89

APPENDIX E2: Toxic potential

	Heavy metals		1. Cadmium			2.Chromium				3. Copper		
	CATEGORY	**Cd** per unit(g)	no. of units	total(Kg)		**Cr** per unit(g)	no. of units	total(Kg)		**Cu** per unit(g)	no. of units	total(Kg)
HW	PC (Monitor+CPU)	3.6277E-05	1588.5	0.06		3.63E-05	1588.5	5.8E-05		150.3557	1588.5	238.8
	Printers	0.26	120	31.20		1.4145	120	1.7E-01		1550	120	186.0
	Projectors	0.0072	23	0.17		0.0648	23	1.5E-03		0.576	23	0.0
	Air conditioners	0.286	135.5	38.75		2.21	135.5	3.0E-01		2860	135.5	387.5
			Total	70.18			Total	4.7E-01			Total	812.38
PMB	PC (Monitor+CPU)	3.6277E-05	656	0.02		3.63E-05	656	2.4E-05		150.3557	656	98.6
	Printers	0.26	11	2.86		1.4145	11	1.6E-02		1550	11	17.1
	Projectors	0.0072	4	0.03		0.0648	4	2.6E-04		0.576	4	0.0
	Air conditioners	0.286	50	14.30		2.21	50	1.1E-01		2860	50	143.0
			Total	17.21			Total	1.3E-01			Total	258.7
UDW	PC (Monitor+CPU)	3.6277E-05	823	0.03		3.63E-05	823	3.0E-05		150.3557	823	123.7
	Printers	0.26	20	5.20		1.4145	20	2.8E-02		1550	20	31.0
	Projectors	0.0072	9	0.06		0.0648	9	5.8E-04		0.576	9	0.0
	Air conditioners	0.286	55	15.73		2.21	55	1.2E-01		2860	55	157.3
			Total	21.02			Total	1.5E-01			Total	312.0
				21.02								312.0
EW	PC (Monitor+CPU)	3.6277E-05	405	0.01		3.63E-05	405	1.5E-05		150.3557	405	60.9
	Printers	0.26	9	2.34		1.4145	9	1.3E-02		1550	9	14.0
	Projectors	0.0072	7	0.05		0.0648	7	4.5E-04		0.576	7	0.0
	Air conditioners	0.286	45	12.87		2.21	45	9.9E-02		2860	45	128.7
			Total	15.28			Total	1.1E-01			Total	203.5
MDS	PC (Monitor+CPU)	3.6277E-05	206	0.01		3.63E-05	206	7.5E-06		150.3557	206	31.0
	Printers	0.26	8	2.08		1.4145	8	1.1E-02		1550	8	12.4
	Projectors	0.0072	4	0.03		0.0648	4	2.6E-04		0.576	4	0.0
	Air conditioners	0.286	28	8.01		2.21	28	6.2E-02		2860	28	80.1
			Total	10.12			Total	7.3E-02			Total	123.4556

	Heavy metals	4. Lead				5. Mercury				6.Nickel		
	CATEGORY	**Pb** per unit(g)	no. of units	total		**Hg** per unit	no. of units	total		**Ni** per unit	no. of units	total
HW	PC (Monitor+CPU)	16.94	1588.5	26.91		0.001	1588.5	0.002		0.008848	1588.5	14.05
	Printers	1.14	120	0.14		0	120	0.000		0.062	120	7.44
	Projectors	0.01	23	0.00		0	23	0.000		0.0288	23	0.66
	Air conditioners	5.20	135.5	0.70		0	135.5	0.000		1.17	135.5	158.54
			Total	27.75			Total	0.002			Total	180.69
PMB	PC (Monitor+CPU)	16.94	656	11.11		0.001	656	0.001		0.008848	656	5.80
	Printers	1.14	11	0.01		0	11	0.000		0.062	11	0.68
	Projectors	0.01	4	0.00		0	4	0.000		0.0288	4	0.12
	Air conditioners	5.20	50	0.26		0	50	0.000		1.17	50	58.50
			Total	11.38			Total	0.001			Total	65.10
UDW	PC (Monitor+CPU)	16.94	823	13.94		0.001	823	0.001		0.008848	823	7.28
	Printers	1.14	20	0.02		0	20	0.000		0.062	20	1.24
	Projectors	0.01	9	0.00		0	9	0.000		0.0288	9	0.26
	Air conditioners	5.20	55	0.29		0	55	0.000		1.17	55	64.35
			Total	14.25			Total	0.001			Total	73.13
EW	PC (Monitor+CPU)	16.94	405	6.86		0.001	405	0.000		0.008848	405	3.58
	Printers	1.14	9	0.01		0	9	0.000		0.062	9	0.56
	Projectors	0.01	7	0.00		0	7	0.000		0.0288	7	0.20
	Air conditioners	5.20	45	0.23		0	45	0.000		1.17	45	52.65
			Total	7.10			Total	0.000			Total	56.99
MDS	PC (Monitor+CPU)	16.94	206	3.49		0.001	206	0.000		0.008848	206	1.82
	Printers	1.14	8	0.01		0	8	0.000		0.062	8	0.50
	Projectors	0.01	4	0.00		0	4	0.000		0.0288	4	0.12
	Air conditioners	5.20	28	0.15		0	28	0.000		1.17	28	32.76
			Total	3.64			Total	0.000			Total	35.19

	Heavy metals	7.Zinc		
	CATEGORY	**Zn** per unit	no. of units	total(Kg)
H W	PC (Monitor+CPU)	0.05	1588.5	0.07
	Printers	0.83	120	0.10
	Projectors	0.43	23	0.01
	Air conditioners	0.73	135.5	0.10
			Total	0.28
P M B	PC (Monitor+CPU)	0.00	656	0.00
	Printers	0.83	11	0.01
	Projectors	0.04	4	0.00
	Air conditioners	0.73	50	0.04
			Total	0.05
U D W	PC (Monitor+CPU)	0.00	823	0.00
	Printers	0.83	20	0.02
	Projectors	0.04	9	0.00
	Air conditioners	0.73	55	0.04
			Total	0.06
E W	PC (Monitor+CPU)	0.00	405	0.00
	Printers	0.83	9	0.01
	Projectors	0.04	7	0.00
	Air conditioners	0.73	45	0.03
			Total	0.04
M D S	PC (Monitor+CPU)	0.00	206	0.00
	Printers	0.83	8	0.01
	Projectors	0.04	4	0.00
	Air conditioners	0.73	28	0.02
			Total	0.03

APPENDIX E3: Printed circuit boards (Material composistion)

			Desktop PC		Printer		Projector		Air conditioner	
	Metals	%	Mass(g)	Total per unit	Mass(g)	Total per unit	Mass(g)	Total per unit	Mass(g)	Total per unit
1	Cu	18	1025	184.5	875	8.75	415	74.7	325	242.775
2	Fe	5	1025	51.25	875	17.5	415	20.75	325	67.4375
3	Al	5	1025	51.25	875	26.25	415	20.75	325	67.4375
4	Sn	3.5	1025	35.875	875	35	415	14.525	325	47.20625
5	Pb	3	1025	30.75	875	43.75	415	12.45	325	40.4625
6	Ni	3	1025	30.75	875	52.5	415	12.45	325	40.4625
7	Zn	1.5	1025	15.375	875	61.25	415	6.225	325	20.23125
8	Sb	0.3	1025	3.075	875	70	415	1.245	325	4.04625
	Ceramics	%	Mass(g)	Total per unit	Mass(g)	Total per unit	Mass(g)	Total per unit	Mass(g)	Total per unit
9	SiO2	15	1025	153.75	875	78.75	415	62.25	325	202.3125
10	Al2O3	7	1025	71.75	875	87.5	415	29.05	325	94.4125
11	Alkali-earth oxide	6	1025	61.5	875	96.25	415	24.9	325	80.925
12	Titanates-micas	3	1025	30.75	875	105	415	12.45	325	40.4625
	Plastics	%	Mass(g)	Total per unit	Mass(g)	Total per unit	Mass(g)	Total per unit	Mass(g)	Total per unit
13	PE	12	1025	123	875	113.75	415	49.8	325	161.85
14	PP	4	1025	41	875	122.5	415	16.6	325	53.95
15	PS	4	1025	41	875	131.25	415	16.6	325	53.95
16	Epoxy	4	1025	41	875	140	415	16.6	325	53.95
17	Pvc	2	1025	20.5	875	148.75	415	8.3	325	26.975
18	Ptpe	1.5	1025	15.375	875	157.5	415	6.225	325	20.23125
	Precious Metals	PPM	Mass(g)	Total per unit	Mass(g)	Total per unit	Mass(g)	Total per unit	Mass(g)	Total per unit
19	Au	900	1025	0.9225	875	0.000807188	415	3.34983E-07	325	1.08869E-10
20	Ag	2200	1025	2.255	875	0.001973125	415	8.18847E-07	325	2.66125E-10
21	Pd	1975	1025	2.024375	875	0.001771328	415	7.35101E-07	325	2.38908E-10
22	Pt	12.5	1025	0.0128125	875	1.12109E-05	415	4.65254E-09	325	1.51208E-12
23	Co	1999.5	1025	2.0494875	875	0.001793302	415	7.4422E-07	325	2.41872E-10

APPENDIX E4: Material value

		1						2				
	CATEGORY	**Al** (G/ Per unit)	**Units**	**Al** (Total) KG	Price per gram	Total **Al**		**CU** (G/ Per unit)	**Units**	**CU** (Total) KG	Price per gram	Total **CU**
H W	PC (Monitor+CPU)	1000.17	1588.5	1588.770045	0.015	23831.55		604.7	1588.5	960.56595	0.05	48028.3
	Printers	6720	120	806.4	0.015	12096		1550	120	186	0.05	9300
	Projectors	846	23	19.458	0.015	291.87		576	23	13.248	0.05	662.4
	Air conditioners	1612	135.5	218.426	0.015	3276.39		4420	135.5	598.91	0.05	29945.5
					Total	39495.81					Total	87936.2
P M B	PC (Monitor+CPU)	1000.17	656	656.11152	0.015	9841.673		604.7	656	396.6832	0.05	19834.16
	Printers	6720	11	73.92	0.015	1108.8		1550	11	17.05	0.05	852.5
	Projectors	846	4	3.384	0.015	50.76		576	4	2.304	0.05	115.2
	Air conditioners	1612	50	80.6	0.015	1209		4420	50	221	0.05	11050
					Total	12210.23					Total	31851.86
U D W	PC (Monitor+CPU)	1000.17	823	823.13991	0.015	12347.1		604.7	823	497.6681	0.05	24883.41
	Printers	6720	20	134.4	0.015	2016		1550	20	31	0.05	1550
	Projectors	846	9	7.614	0.015	114.21		576	9	5.184	0.05	259.2
	Air conditioners	1612	55	88.66	0.015	1329.9		4420	55	243.1	0.05	12155
					Total	15807.21					Total	38847.61
E W	PC (Monitor+CPU)	1000.17	656	656.11152	0.015	9841.673		604.7	656	396.6832	0.05	19834.16
	Printers	6720	11	73.92	0.015	1108.8		1550	11	17.05	0.05	852.5
	Projectors	846	4	3.384	0.015	50.76		576	4	2.304	0.05	115.2
	Air conditioners	1612	50	80.6	0.015	1209		4420	50	221	0.05	11050
					Total	12210.23					Total	31851.86
M D S	PC (Monitor+CPU)	1000.17	206	206.03502	0.015	3090.525		604.7	206	124.5682	0.05	6228.41
	Printers	6720	8	53.76	0.015	806.4		1550	8	12.4	0.05	620
	Projectors	846	4	3.384	0.015	50.76		576	4	2.304	0.05	115.2
	Air conditioners	1612	28	45.136	0.015	677.04		4420	28	123.76	0.05	6188
					Total	4624.725					Total	13151.61

		3					4					5				
	CATEGORY	GOLD (G/ Per unit)	**Units**	GOLD (Total) KG	Price per gram	Total Gold	NI (G/ Per unit)	**Units**	NI (Total) KG	Price per gram	Total NI	Pt (G/ Per unit)	**Units**	Pt (Total) KG	Price per gram	Total Pt
	PC (Monitor+CPU)	0.11	1588.5	0.174735	886.88	154969	5.125	1588.5	8.1410625	0.15	1221.159	0.014	1588.5	0.0219213	408.58	8956.604754
H W	Printers	24	120	2.88	886.88	2554214	35	120	4.2	0.15	630	18.000	120	2.16	408.58	882532.8
	Projectors	30	23	0.69	886.88	611947.2	22	23	0.506	0.15	75.9	25.000	23	0.575	408.58	234933.5
	Air conditioners	0	135.5	0	886.88	0	0	135.5	0	0.15	0		135.5	0	408.58	0
					Total	3321131				Total	1927.059				Total	1126422.905
	PC (Monitor+CPU)	0.11	656	0.07216	886.88	63997.26	5.125	656	3.362	0.15	504.3	0.014	656	0.0090528	408.58	3698.793024
P M B	Printers	24	11	0.264	886.88	234136.3	35	11	0.385	0.15	57.75	18.000	11	0.198	408.58	80898.84
	Projectors	30	4	0.12	886.88	106425.6	22	4	0.088	0.15	13.2	25.000	4	0.1	408.58	40858
	Air conditioners	0	50	0	886.88	0	0	50	0	0.15	0		50	0	408.58	0
					Total	404559.2				Total	575.25				Total	125455.633
	PC (Monitor+CPU)	0.11	823	0.09053	886.88	80289.25	5.125	823	4.217875	0.15	632.6813	0.014	823	0.0113574	408.58	4640.406492
U D W	Printers	24	20	0.48	886.88	425702.4	35	20	0.7	0.15	105	18.000	20	0.36	408.58	147088.8
	Projectors	30	9	0.27	886.88	239457.6	22	9	0.198	0.15	29.7	25.000	9	0.225	408.58	91930.5
	Air conditioners	0	55	0	886.88	0	0	55	0	0.15	0		55	0	408.58	0
					Total	745449.2				Total	767.3813				Total	243659.7065
	PC (Monitor+CPU)	0.11	656	0.07216	886.88	63997.26	5.125	656	3.362	0.15	504.3	0.014	656	0.0090528	408.58	3698.793024
E W	Printers	24	11	0.264	886.88	234136.3	35	11	0.385	0.15	57.75	18.000	11	0.198	408.58	80898.84
	Projectors	30	4	0.12	886.88	106425.6	22	4	0.088	0.15	13.2	25.000	4	0.1	408.58	40858
	Air conditioners	0	50	0	886.88	0	0	50	0	0.15	0		50	0	408.58	0
					Total	404559.2				Total	575.25				Total	125455.633
	PC (Monitor+CPU)	0.11	206	0.02266	886.88	20096.7	5.125	206	1.05575	0.15	158.3625	0.014	206	0.0028428	408.58	1161.511224
M D S	Printers	24	8	0.192	886.88	170281	35	8	0.28	0.15	42	18.000	8	0.144	408.58	58835.52
	Projectors	30	4	0.12	886.88	106425.6	22	4	0.088	0.15	13.2	25.000	4	0.1	408.58	40858
	Air conditioners	0	28	0	886.88	0	0	28	0	0.15	0		28	0	408.58	0
					Total	296803.3				Total	213.5625				Total	100855.0312

		6					7					8				
	CATEGORY	NI (G/ Per unit)	Units	NI (Total) KG	Price per gram	Total NI	Pt (G/ Per unit)	Units	Pt (Total) KG	Price per gram	Total Pt	Silver (G/ Per unit)	Units	Silver (Total) KG	Price per gram	Total Silver
H W	PC (Monitor+CPU)	5.125	1588.5	8.14	0.15	1221.16	0.0138	1588.5	0.02	408.58	8956.605	3.882	1588.5	6.17	12.5	77.08
	Printers	35	120	4.20	0.15	630.00	18	120	2.16	408.58	882532.8	30	120	3.60	12.5	45.00
	Projectors	22	23	0.51	0.15	75.90	25	23	0.58	408.58	234933.5	15	23	0.35	12.5	4.31
	Air conditioners	0	135.5	0.00	0.15	0.00	0	135.5	0.00	408.58	0	0	135.5	0.00	12.5	0.00
					Total	1927.06				Total	1126423				Total	126.39
P M B	PC (Monitor+CPU)	5.125	656	3.36	0.15	504.30	0.0138	656	0.01	408.58	3698.793	3.882	656	2.55	12.5	31.83
	Printers	35	11	0.39	0.15	57.75	18	11	0.20	408.58	80898.84	30	11	0.33	12.5	4.13
	Projectors	22	4	0.09	0.15	13.20	25	4	0.10	408.58	40858	15	4	0.06	12.5	0.75
	Air conditioners	0	50	0.00	0.15	0.00	0	50	0.00	408.58	0	0	50	0.00	12.5	0.00
					Total	575.25				Total	125455.6				Total	36.71
U D W	PC (Monitor+CPU)	5.125	823	4.22	0.15	632.68	0.0138	823	0.01	408.58	4640.406	3.882	823	3.19	12.5	39.94
	Printers	35	20	0.70	0.15	105.00	18	20	0.36	408.58	147088.8	30	20	0.60	12.5	7.50
	Projectors	22	9	0.20	0.15	29.70	25	9	0.23	408.58	91930.5	15	9	0.14	12.5	1.69
	Air conditioners	0	55	0.00	0.15	0.00	0	55	0.00	408.58	0	0	55	0.00	12.5	0.00
					Total	767.38				Total	243659.7				Total	49.12
E W	PC (Monitor+CPU)	5.125	656	3.36	0.15	504.30	0.0138	656	0.01	408.58	3698.793	3.882	656	2.55	12.5	31.83
	Printers	35	11	0.39	0.15	57.75	18	11	0.20	408.58	80898.84	30	11	0.33	12.5	4.13
	Projectors	22	4	0.09	0.15	13.20	25	4	0.10	408.58	40858	15	4	0.06	12.5	0.75
	Air conditioners	0	50	0.00	0.15	0.00	0	50	0.00	408.58	0	0	50	0.00	12.5	0.00
					Total	575.25				Total	125455.6				Total	36.71
M D S	PC (Monitor+CPU)	5.125	206	1.06	0.15	158.36	0.0138	206	0.00	408.58	1161.511	3.882	206	0.80	12.5	10.00
	Printers	35	8	0.28	0.15	42.00	18	8	0.14	408.58	58835.52	30	8	0.24	12.5	3.00
	Projectors	22	4	0.09	0.15	13.20	25	4	0.10	408.58	40858	15	4	0.06	12.5	0.75
	Air conditioners	0	28	0.00	0.15	0.00	0	28	0.00	408.58	0	0	28	0.00	12.5	0.00
					Total	213.5625				Total	100855				Total	13.74615

		Scrap metal prices South Africa	MK Kruger (24-10-2020)
	Scrap metal value	R/Kg	R/g
1	Aluminum	15	0.015
2	Copper	50	0.05
3	Iron	10	0.01
4	steel	35	0.035
5	tin	45	0.045
6	zinc	80	0.08
7	nickel	150	0.15
8	gold		12.5
9	silver		12.5
10	pt		408.6

APPENDIX E5: Landfilling

Campus	Total wieght (KG)	waste per year (KG)	Collection Charge	Total Collection Charge	Gate Fees(Per ton)	Total Gate fees(Per year)	**Total (Per year)**
Howard	38382.5	6159.86	R 337.87	R 2,081.21	R 381.00	R 2,346.91	R 4,428.12
PMB	17269.8	2817.2	R 337.87	R 951.84	R 381.00	R 1,073.35	R 2,025.19
Westville	22091.9	801.23	R 337.87	R 270.71	R 381.00	R 305.27	R 575.98
Edgewood	10796.1	2188.9	R 337.87	R 739.56	R 381.00	R 833.97	R 1,573.53
Medical	7854.2	1475.64	R 337.87	R 498.57	R 381.00	R 562.22	R 1,060.79
			Total	R 4,541.88		**Total**	R 9,663.60

Campus	**Landfill**
Howard	Bisasar road
PMB	Msunduzi
Westville	Bisasar road
Edgewood	Marrianhill
Medical	Bisasar road

Note:
Gate fees are eThekwini average
Collection charges are area dependent

Collection Charge		
Labour(Hr)	R 50	R 150
Diesel	R 14.20	R 56.80
Truck	0	R 300
Tons	-	12
Total		R 6,081.60
Per ton		R 337.87

APPENDIX E6: Recycling

			Fixed Cost		Variable cost								
Campus	Total wieght (KG)	waste per year (KG)	Equipment cost (Per ton)	Rent Cost (Per ton)	Labour (Per ton)	Labour (Total)	Energy(Per/ton)	Energy(Total)	Material (Per/ton)	Material (Total)	Transport (Per/ton)	Transport (Total)	Total
Howard	38382.5	6155.81	R 125	R 125	R 1,344	R 8,273	288	R 1,773	R 50	R 308	R 294.87	R 1,815.14	R 13,708.17
PMB	17269.8	3453.96	R 125	R 125	R 1,344	R 4,642	288	R 995	R 50	R 173	R 294.87	R 1,018.46	R 7,691.51
Westville	22091.9	2817.2	R 125	R 125	R 1,344	R 3,786	288	R 811	R 50	R 141	R 294.87	R 830.70	R 6,273.53
Edgewood	10796.1	2159.22	R 125	R 125	R 1,344	R 2,902	288	R 622	R 50	R 108	R 294.87	R 636.68	R 4,808.30
Medical	7854.2	1570.84	R 125	R 125	R 1,344	R 2,111	288	R 452	R 50	R 79	R 294.87	R 463.19	R 3,498.05

Revenue

		Customer fee		Resale system/components		
Campus	Material recovery	Per ton	Total	Per ton	Total	**Total**
Howard	80%	0	0	R24,387.15	R150,122.64	R150,122.64
PMB	80%	0	0	R24,387.15	R84,232.23	R84,232.23
Westville	80%	0	0	R24,387.15	R68,703.47	R68,703.47
Edgewood	80%	0	0	R24,387.15	R52,657.22	R52,657.22
Medical	80%	0	0	R24,387.15	R38,308.31	R38,308.31

	Name	Description	Customer fee	Equipment (Per ton)	Labour(Per hr)	Energy	Materials	Transport
1	Ewaste tech It recycling	Small size (500 Kg per day)	R 0	R 100	R 40	R 322	R 60	R 324
2	Electronic cementary	Small size (500 Kg per day)	R 0	R 125	R 50	R 275	R 52	R 268
3	Ewaste Africa	Medium size (1 ton per day)	R 0	R 150	R 36	R 267	R 39	R 285
	Average	-	R 0	R 125	R 42	R 288	R 50	R 295

APPENDIX E7: Resale of electronics

		Total Units	low	No Units	Total	Moderate	No Units	Total	Excellent	No Units	Total
	Desktop	1588.5	R 1,200	159	R 190,620	R 4,000	159	R 635,400	R 5,000	1271	R 6,354,000
H	Projectors	120	R 600	12	R 7,200	R 2,000	12	R 24,000	R 3,500	96	R 336,000
W	AC	23	R 800	2	R 1,840	R 3,000	2	R 6,900	R 4,000	18	R 73,600
	Printers	135.5	R 5,000	14	R 67,750	R 16,000	14	R 216,800	R 22,000	108	R 2,384,800
				Total	R 267,410		Total	R 883,100		Total	R 9,148,400
		Total Units	low	No Units	Total	Moderate	No Units	Total	Excellent	No Units	Total
P	Desktop	656	R 1,200	66	R 78,720	R 4,000	33	R 131,200	R 5,000	590	R 2,952,000
M	Projectors	11	R 600	1	R 660	R 2,000	1	R 1,100	R 3,500	10	R 34,650
B	AC	4	R 800	0	R 320	R 3,000	0	R 600	R 4,000	4	R 14,400
	Printers	50	R 5,000	5	R 25,000	R 16,000	3	R 40,000	R 22,000	45	R 990,000
				Total	104700		Total	172900		Total	R 3,991,050
		Total Units	low	No Units	Total	Moderate	No Units	Total	Excellent	No Units	Total
U	Desktop	823	R 1,200	82	R 98,760	R 4,000	41	R 164,600	R 5,000	741	R 3,703,500
D	Projectors	20	R 600	2	R 1,200	R 2,000	1	R 2,000	R 3,500	18	R 63,000
W	AC	9	R 800	1	R 720	R 3,000	0	R 1,350	R 4,000	8	R 32,400
	Printers	55	R 5,000	6	R 27,500	R 16,000	3	R 44,000	R 22,000	50	R 1,089,000
				Total	R 128,180		Total	R 211,950		Total	R 4,887,900
		Total Units	low	No Units	Total	Moderate	No Units	Total	Excellent	No Units	Total
M	Desktop	206	R 1,200	21	R 24,720	R 4,000	10	R 41,200	R 5,000	185	R 927,000
D	Projectors	8	R 600	1	R 480	R 2,000	0	R 800	R 3,500	7	R 25,200
S	AC	4	R 800	0	R 320	R 3,000	0	R 600	R 4,000	4	R 14,400
	Printers	28	R 5,000	3	R 14,000	R 16,000	1	R 22,400	R 22,000	25	R 554,400
				Total	R 39,520		Total	R 65,000		Total	R 1,521,000
		Total Units	low	No Units	Total	Moderate	No Units	Total	Excellent	No Units	Total
E	Desktop	405	R 1,200	41	R 48,600	R 4,000	20	R 81,000	R 5,000	365	R 1,822,500
W	Projectors	9	R 600	1	R 540	R 2,000	0	R 900	R 3,500	8	R 28,350
C	AC	7	R 800	1	R 560	R 3,000	0	R 1,050	R 4,000	6	R 25,200
	Printers	45	R 5,000	5	R 22,500	R 16,000	2	R 36,000	R 22,000	41	R 891,000
				Total	R 72,200		Total	R 118,950		Total	R 2,767,050

Table E1: Description of the condition of e-waste

	Description
Low	Requires major repairs and components need to be changed
Moderate	Requires some repairs, and maintanance
Excellent	Requires no repairs

Table E2: Quoted prices from second-hand resellers

		Desktop			Projectors			Air conditioning units			Printers		
	Name of reseller	Low	Moderate	Excellent	Low	Moderate	Excellent	Low	Moderate	Excellent	Low	Moderate	Excellent
1	Africa PC	1250	4500	5400	650	1800	3000	850	3500	4500	4500	18000	25000
2	Refurb. SA	1400	3500	4650	450	2200	4000	775	2750	3000	6000	15000	20000
3	Just PC's	950	4000	4850	700	2000	3500	775	2750	4500	4500	15000	
	Average	1200	4000	5000	600	2000	3500	800	3000	4000	5000	16000	15000

APPENDIX E8: MRF OPERATIONS

Campus	Total wieght (KG)	waste per year (KG)	Fixed cost	Total	Operational cost per ton	Total Op cost	Labour per ton	Total labour	Total
Howard	23040	4608	R 325	R 1,498	R 408	R 1,880	R 640	R 2,949	R 6,327
PMB	9222	1844.4	R 325	R 599	R 408	R 753	R 640	R 1,180	R 2,532
Westville	11933.5	2386.7	R 325	R 776	R 408	R 974	R 640	R 1,527	R 3,277
Edgewood	5872.5	1174.5	R 325	R 382	R 408	R 479	R 640	R 752	R 1,613
Medical	2987	597.4	R 325	R 194	R 408	R 244	R 640	R 382	R 820

Operational cost		
Electricity		R 288
Materials		R 120
	Total	R 408

Fixed Cost	
Rent	R 200
Equipment	R 125
Total	R 325

APPENDIX E9: OPERATIONS EMISSIONS

TRANSPORTATION								
Campus	Total wieght (KG)	waste per year (Ton)	Fuel (*l*)	Total	transportation KG/CO2 (Per ton)	Total C02		
Howard	38382.5	7.6765	14.6	112.0769	40.3	309.36295		
PMB	17269.8	3.45396	14.6	50.427816	40.3	139.194588		
Westville	22091.9	4.41838	3.2	14.138816	8.9	39.323582		
Edgewood	10796.1	2.15922	3.2	6.909504	8.9	19.217058		
Medical	7854.2	1.57084	3.2	5.026688	8.9	13.980476		

Pyrolosis								
Campus	Total Weight of PCB's (Kg)	grams	CO (mg/g)	Total CO (Kg)	CO2 (mg/g)	Total CO2 (Kg)	CH3 (mg/g)	Total CH3 (Kg)
Howard	1,786.80	1,786,795.00	0.16	285.89	150	268,019.25	180	321,623.10
PMB	699.94	699,935.00	0.16	111.99	150	104,990.25	180	125,988.30
Westville	882.69	882,685.00	0.16	141.23	150	132,402.75	180	158,883.30
Edgewood	440.53	440,530.00	0.16	70.48	150	66,079.50	180	79295.4
Medical	228.91	228,910.00	0.16	36.63	150	34336.5	180	41203.8