Minerals to Metals Initiative

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Exploring the potential for local end-processing of e-waste in South Africa

DISSERTATION IN FULFILMENT OF A MASTER OF SCIENCE DEGREE IN CHEMICAL ENGINEERING

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Executive Summary

E-waste is one of the fastest-growing waste streams in the world, and South Africa (SA) is no exception. This is driven by increased consumer demand and access to electrical and electronic equipment, in addition to perceived equipment obsolescence, and rapid advancements in technology. E-waste recycling presents an opportunity in providing a source of secondary resources such as metals, plastics and glass, as well as employment and economic opportunities in both developed and developing countries. Furthermore, the diversion of this waste stream from landfills or dumps prevents additional land use and the potential negative impacts on human health and the environment.

E-waste collection and upgrading is a relatively small-scale but growing industry in SA. Only 12% of e-waste generated was estimated to be recycled in 2015. Most of SA's e-waste volumes are inaccessible due to lack of formal take-back schemes, lack of consumer awareness, as well as e-waste being kept in storage or disposed of in landfills. E-waste recyclers in SA generally carry out collection, dismantling and sorting, refurbishing, as well as pre-processing of value fractions. There is currently limited local end-processing capacity, therefore partially upgraded value fractions are prepared for export, while non-viable fractions are stockpiled or disposed of in local landfills.

The business case for local end-processing of e-waste value fractions, particularly metals, does not seem feasible due to the inconsistent and insufficient volumes available. Furthermore, SA faces unique socio-economic challenges such as an unregulated yet well-established informal sector. Additionally, the legal framework presents many inhibitors for e-waste recyclers.

This research study builds upon the knowledge that there is a limited understanding of the feasibility of existing e-waste end-processing technologies for implementation in the South African socio-economic and legislative context. Therefore, this research intends to find out what are the key barriers and enablers to implementing e-waste end-processing technologies in SA. Qualitative research methods were used to uncover the current challenges faced by local recyclers and other stakeholders in the value chain. The data collection thus took the form of interviews, site visits and desktop research.

The findings show that the e-waste recycling industry in SA is undergoing many new developments in terms of research and investment interest, as well as the anticipated outcomes from the recent submissions of Industry Waste Management Plans (IndWMP). The industry shows potential as an emerging secondary resource economy, however, the extent to which it will mature is dependent on the organisation of its collection network as well as the development of local end-processing and manufacturing capacity.

The collection network and infrastructure are currently supported by both informal and formal recyclers who provide a diversity of collection strategies and a wide network of e-waste sources. However, efforts to increase recycling rates by accessing volumes in storage and increasing consumer awareness and engagement is necessary. Besides the economies of scale required to support the development of local end-processing, alternative technologies to large-scale smelting should be considered for the SA context. While this is seen through initiatives by SA Precious Metals, end-processing technologies is still inaccessible to small and medium recyclers due to cash flow issues as well as cherry-picking of high-grade materials. Therefore, recyclers require further support in terms of dealing with non-viable fractions. This includes research and investments into technologies and business models for the recycling of low-value materials including plastics, as well as subsidies for the cost of safe disposal or treatment of these fractions. Additionally, acquisition of product markets and an increase in manufacturing capacity is necessary to accelerate industry development.

The legislative framework also poses limitations on recyclers in the e-waste value chain, stemming from the legal definition of e-waste as a liability as opposed to a resource. While the legislation is unlikely to change, provisions to relieve any legal barriers should be implemented. This includes permissions for pilot projects to test new technologies, as well as legal support for smaller recyclers in the form of consultancy as well as guidelines for sustainable waste management practices should be provided.

Finally, while there are many challenges present in the e-waste recycling industry today, the IndWMP offers an opportunity for collaboration between key stakeholders, including the relevant government bodies. Plans have been submitted and the outcomes of approved plans will be revealed at the beginning of 2019. The plans offer solutions for recycling subsidies, increasing the collection and recycling rates, as well as investment into technology, research and enterprise development. However, successful implementation of these plans will only occur if integration and collaboration of the local e-waste community prevail over greed and the struggle for power.

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EEA	European Environment Agency
<	Less than, symbol
>	Greater than, symbol
ABS	Acrylonitrile Butadiene Styrene
Ag	Silver
Al	Aluminium
Au	Gold
Beneficiation	In the mining or extractive metallurgy industry, beneficiation is any process that improves the economic value of the ore by removing the gangue minerals, which results in a higher-grade product and a waste stream.
BFR	Brominated Flame Retardant
Bo2W	Best-Of-2-Worlds
CBD	Central Business District
CD	Compact Disc
Cd	Cadmium
CE	Circular Economy
COCT	City of Cape Town
CPU	Central Processing Units
CRT	Cathode Ray Tube
CSIR	Council of Scientific and Industrial Research
Cu	Copper
DANCED	Danish Cooperation for Environment and Development
DANIDA	Danish International Development Agency
DEA	Department of Environmental Affairs
DST	Department of Science and Technology

DTI	Department of Trade and Industry
DVD	Digital Versatile Disc
ECA	Environmental Conservation Act (Act 73 Of 1989, As Amended)
EEE	Electronic and Electrical Equipment
EIA	Environmental Impact Assessment
EMF	The Ellen Macarthur Foundation
EMPA	Swiss Federal Laboratories for Materials Testing and Research
End-processing	End-processing (or downstream processing) refers to any recovery, purification, or product refining process step.
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
ERA	E-waste Recycling Authority
EU	European Union
eWASA	e-Waste Association of South Africa
EWIT	E-Waste Implementation Toolkit
Fe	Iron
Formal	Legally compliant and registered with relevant legal bodies.
Hazard	A source of potential harm, caused by a particular type of energy (mechanical, chemical, biological, etc.)
HIPS	High Impact Polystyrene
HP	Hewlett-Packard
IBM	International Business Machines Corporation
ICT	Information and Communication Technology
In	Indium
IndWMP	Industry Waste Management Plan
Informal	Legally non-compliant and/or not registered with relevant legal bodies.

IP&WM	Integrated Pollution and Waste Management
IPWIS	Integrated Pollution and Waste Information System
ISO	International Organisation for Standardization
ITA	Information Technology Association
ITAC	International Trade Administration Commission of South Africa
IWM	Integrated Waste Management
IWMSA	Institute of Waste Management of Southern Africa
kt	kilotonnes
LCD	Liquid Crystal Display
Li	Lithium
LPUR	Law for the Promotion of Effective Utilization of Resources
m^2	Square metres
m^3	Cubic metres
MRA	Metals Recycling Association of SA
MRT	Mercury Recovery Technology
MtM	Mineral to Metals
NAP	National Action Plans
NECSA	Nuclear Energy Corporation of SA
NEMA	National Environmental Management Act
NEMWA	National Environmental Management: Waste Act, 2008 (Act 59 Of 2008)
NEMWAA	National Environmental Management: Waste Amendment Act, 2014 (Act 26 Of 2014)
NGO	Non-Governmental Organisations
NPC	Non-Profit Company
NRF	National Recycling Forum
NRG	New Reclamation Group

NWMS	National Waste Management Strategy
OECD	Organisation for Economic Co-Operation and Development
OEM	Original Equipment Manufacturer
ORDEE	Swiss Ordinance on The Return, the Taking Back & the Disposal of Electronic and Electrical Equipment
Pb	Lead
PC	Polycarbonate
PC (in Just PCs)	Personal Computer
PCB	Printed Circuit Boards
Pd	Palladium
PE	Polyethylene
PET	Polyethylene Terephthalate
PETCO	Polyethylene Terephthalate Recycling Company
PGM	Platinum Group Metals
PP	Polypropylene
PPE	Personal Protective Equipment
PPO	Poly P-Phenylene Oxide
PRASA	Paper Recycling Association of SA
PRO	Producer Responsibility Organisation
PVC	Polyvinyl Chloride
RAG	Recycling Action Group
RDI	Research, Development and Innovation
REDISA	Recycling and Economic Development Initiative of South Africa
REE	Rare Earth Elements
RoHS	Restriction of Hazardous Substances
SA	South Africa

SADA	South African Domestic Appliances Association
SAEWA	Southern African E-Waste Alliance
SAPS	South African Police Service
SAWIS	South African Waste Information System
SECO	Swiss State Secretariat for Economic Affairs
SEZ	Special Economic Zone
SGEP	Swiss Global E-Waste Program
SME	Small and Medium Enterprises
Sn	Tin
SRI	Sustainable Recycling Industries
StEP	Solving the E-Waste Problem
SWICO	Swiss Trade Association of the Information, Communication and Organisation Industry
TIA	Technology Innovation Agency
UCT	University of Cape Town
UK	United Kingdom
UNEP	United Nations Environment Programme
UNU	United Nations University
URC	Universal Recycling Company
WEEE	Waste Electronic and Electrical Equipment
WISP	Western Cape Industrial Symbiosis
WMB	Waste Management Bureau
Wt.%	Percentage by weight
ZAR	South African Rands
Zn	Zinc

1 Introduction

The purpose of this study is to investigate the current status of the e-waste management and recycling industry in South Africa (SA) and its advancement towards a secondary resource economy. This involves evaluating the e-waste value chain activities and stakeholder network, as well as further assessing the enablers and inhibitors of the secondary resource economy within the South African context.

This chapter provides the background and context of the research leading up to the research problem statement. Thereafter the project objectives, scope and significance are outlined, followed by a brief overview of the dissertation structure.

1.1 Background

The world is currently undergoing a paradigm shift towards sustainable resource management and environmental stewardship. This shift is the result of the rapid depletion of natural resources, the ever-increasing demand for resources, as well as the increased stress on the natural environment to absorb post-consumer waste and the associated pollution in our industrial society (European Environment Agency [EEA], 2011).

The circular economy (CE) model is one framework to drive this shift. It moves away from the linear model of 'take-make-use-dispose', towards resource efficiency and regeneration (The Ellen MacArthur Foundation [EMF], 2017). A key feature of the CE model is the employment of waste as a supply of secondary resources to enable industrial development (EEA, 2011).

Metals in particular play an important role in industrial development, which is coupled to economic development (United Nations Environment Programme [UNEP], 2010). The minerals extraction industry effects major environmental impacts as a result of mining activities, in addition to the depletion of mineral resources. Recycling and recovery of metals from secondary sources is therefore essential to decrease this burden on the natural environment.

A significant source of secondary metals is waste electronic and electrical equipment (WEEE), also known as e-waste. E-waste is one of the fastest-growing waste streams in the world, and SA is no exception (Baldé et al., 2015; Department of Environmental

Affairs [DEA], 2015a). This is a direct consequence of increased consumer demand and access to electrical and electronic equipment, rapid advancements in technology and limited lifespans of equipment (Lydall, Nyanjowa & James, 2017).

E-waste value fractions include printed circuit boards (PCBs); batteries; ferrous and non-ferrous metal components; plastics; and glass cullet. The major value attraction is PCBs due to its precious metal and high copper content. Therefore, most research into value extraction from e-waste focuses on metal extraction from PCBs (Lee, Song & Yoo, 2007; Wang & Gaustad, 2012; Behnamfard, Salarirad & Veglio, 2013; Akcil et al., 2015).

The e-waste recycling industry not only presents an opportunity in resource reclamation but also offers potential employment and economic opportunities (EEA, 2011; Baldé et al., 2017). Furthermore, the diversion of this waste stream away from landfills or dumps prevents additional land use and limits the potential negative impacts on human health and the environment caused by landfill disposal (Advanced Tropical Environment, 2012). This industry is becoming established in both developed and developing countries, albeit under varying conditions (Widmer et al., 2005; Baldé et al., 2015).

E-waste collection and recycling in SA is a relatively small-scale, but growing industry. Only 12% of e-waste generated in SA was estimated to be recycled in 2015 (GreenCape, 2017). This is not due to the lack of recycling capacity as is implied, but rather a result of inaccessible e-waste volumes, poor engagement of e-waste generators, and an ineffective legislative framework (Finlay, 2005; Lydall, Nyanjowa & James, 2017). Unfortunately, this is the case for most recyclable waste in SA.

E-waste recyclers in SA generally carry out collection, dismantling and sorting, refurbishing, as well as pre-processing of the major value fractions (Lydall, Nyanjowa & James, 2017). There is currently limited local processing and refining capacity for value fractions such as metal, plastics, and glass. Therefore, partially upgraded value fractions are exported, while non-viable fractions are stockpiled or disposed of in local landfills (Bondolfi, 2007; Lydall, Nyanjowa & James, 2017). Furthermore, there are high barriers to entry into activities beyond collection and dismantling. Therefore, these initial stages of the value chain are carried out by small-to-medium scale recyclers, while further separation processes are carried out by larger, more established recyclers.

One study suggests that the business case for local processing and refining of e-waste value fractions, particularly metals, is hindered by the inconsistent and insufficient volumes of e-waste fractions available to achieve the necessary economies of scale. Furthermore, competitive export markets, as well as exclusive and privately-owned local technology solutions, present high barriers to entry into end-processing activities (Lydall, Nyanjowa & James, 2017). Other causes for concern include an unregulated yet well-established informal and semi-formal sector, which is not widely covered in literature in the context of e-waste. Additionally, the legal and regulatory framework remains unclear and ambiguous (Dittke, 2009).

1.2 Problem Statement

The e-waste recycling industry presents promising economic and employment opportunities and is a potential driver of the secondary resource economy agenda. As SA and the rest of the world are becoming increasingly invested in this industry, opportunities for its development and growth should be explored.

Economic opportunities from waste recycling can only be embraced once (i) post-consumer waste is made accessible, (ii) there is a viable business case for recycling and resource recovery, and (iii) there is a market for recovered products (GreenCape, 2017). Although there is limited access to e-waste volumes due to behaviours such as storage and disposal in landfill, there still exists a vibrant and growing recycling industry.

Currently, e-waste processors in SA are mainly collecting, dismantling, and pre-processing e-waste, which produces value fractions such as PCBs, ferrous and non-ferrous metals, plastics and glass. But some non-viable fractions contribute negatively to the economics of recycling, especially for small-to-medium recyclers. These fractions require disposal at considerable cost or end up being dumped illegally.

The raw value fractions are mostly exported to European and Asian markets for further processing and refining due to the limited and exclusive local end-processing industry (Lydall, Nyanjowa & James, 2017). However, there is a growing interest in local end-processing of e-waste fractions, particularly metal extraction and plastics recycling processes.

Processing technologies are well researched and reported on; however, the feasibility and implementation of these technologies in the South African socio-economic context are not well understood. Furthermore, there is limited research on the product markets of recovered value fractions for local processing.

1.3 Research Aim & Objectives

This research study builds upon the knowledge that there is a limited understanding of the feasibility of existing e-waste end-processing technologies for implementation in the South African socio-economic and legislative context. Therefore, this research intends to find out what are the key barriers and enablers to implementing e-waste end-processing technologies in SA.

The following objectives are set as guidelines to fulfil this aim:

1. Develop a deeper understanding of the development and organisation of the e-waste industry in SA.
2. Investigate existing technology options for e-waste end-processing and their feasibility in the South African context.
3. Identify the socio-economic and legislative barriers and enablers for local, small-scale end-processing for value extraction from e-waste.
4. Provide recommendations for the next steps in establishing local e-waste end-processing, addressed to research institutions, industry and relevant government bodies.

1.4 Scope & Significance

The area of interest of this study is to understand and explore the socio-economic context of the e-waste industry in SA. This includes investigation of the e-waste management value chain, stakeholder mapping as well as evaluating the legislative and regulatory framework. Detailed analysis of the Western Cape region was made as well as a high-level national overview. This is due to the limited accessibility of information and stakeholders, as well as time constraints of this research.

This research provides an overview of available technologies and potential process routes but will not include details of the technical, process design. Emphasis is placed on the feasibility of e-waste end-processing in the South African context. The study will be of value to e-waste collectors, recyclers and industry regulators in understanding the opportunities for end-processing as well as the common vision for the industry and how they fit into that.

1.5 Dissertation structure

This dissertation is divided into six chapters:

Chapter 1 introduces the background of the study and sets up its scope and aim.

Chapter 2 provides a literature review outlining the major concepts and theories used in the investigation.

Chapter 3 presents the methodology and research approach.

Chapter 4 presents an overview of the development of the South African e-waste industry with an emphasis on the legislative environment.

Chapter 5 outlines the current e-waste industry in South Africa in terms of the value chain activities and stakeholder network.

Chapter 6 concludes this report, summarizing the main findings and their implications, as well as presents recommendations for further research.

Thereafter the reference list and appendices follow.

2 Literature Review

The previous chapter outlined the background and objectives of the study, which is to determine the opportunities for local end-processing of e-waste in SA. This chapter will present a review of the literature outlining various approaches to e-waste management and its positioning as a secondary resource economy.

2.1 The Circular Economy

This research study falls within the theme of the circular economy (CE), which is a model to describe the continuous flow of resources, that is, materials and energy, within a closed-loop economy (Geng et al., 2009). The CE is a huge contributor to sustainable waste management policy and practices today. It aims to move away from the linear economic model of take-make-use-dispose towards a closed-loop economic model incorporating recycling and resource recovery interventions (EMF, 2017). This shift ensures the minimization of both the overall waste generation as well as the amount of new raw materials entering the system. The shift from linear to circular requires innovative approaches to product design, business models, reverse consumer cycles, as well as favourable system conditions such as collaboration, global economics, and access to funding.

The linear to circular shift for finite resources is illustrated in Figure 1. The linear model is illustrated as the introduction of raw materials, parts and product manufacture, service provision to the user, and finally disposal. At each stage of the linear model, CE interventions can be implemented to achieve the overall aim, which is to limit the introduction of new raw materials and minimising disposal of resources. This is done by prolonging the product lifespan through sharing and maintenance of the product. Reuse and redistribution encourage a hand-me-down culture of products to multiple users. Thereafter, refurbishment and remanufacture of products and recycling of parts can further extend the product life and use through technology interventions. Lastly, interventions at the product design stage can be implemented to complement all other interventions.

Product design interventions include (Bocken et al., 2016):

i) Slowing resource loops: design products with longer lifespans as well as designing for ease of repair and refurbishment, such as modular design.

ii) Closing resource loops: designing products with the intention of recycling by incorporating features such as ease of disassembly.

iii) Narrowing resource loops: using fewer overall resources and less hazardous resources in product manufacture to reduce the resource footprint.

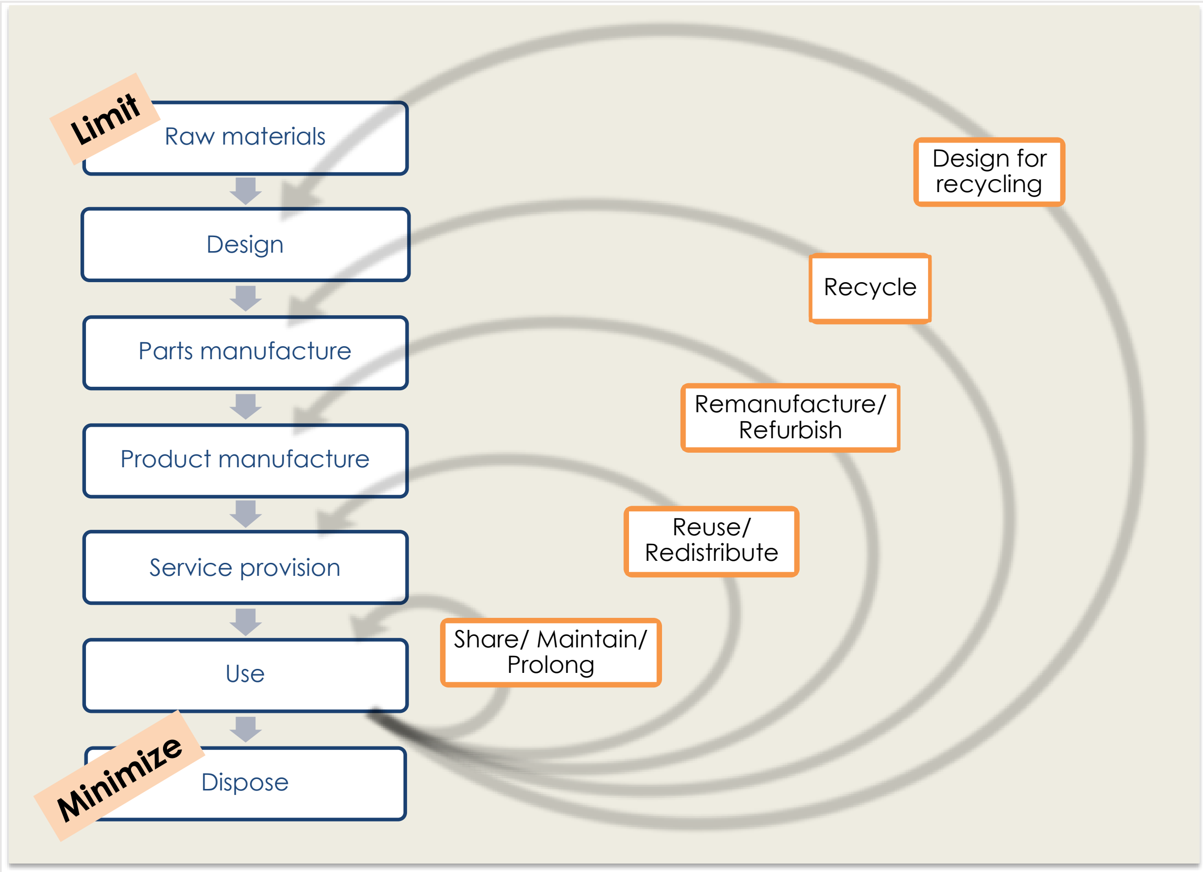

Figure 1: Shifting from the Linear to the Circular Economy Model (adapted from EMF, 2017)

It should be noted that the CE model is not entirely a closed loop because it is still growing, which means that there is still input of new resources continuing to accumulate in the cycle. Furthermore, there is disposal of non-recyclable residues as well as losses due to unnecessary disposal or unavoidable dispersion – which is attributed to entropy generation. This is further explored by Cullen (2017), in which the CE is recognised as an ideal model rather than that possible to attain fully.

2.1.1 Circular Economy Principles

The concept of the CE has developed from many schools of thought, which include the following, (EMF, 2017):

- cradle-to-cradle,
- biomimicry,
- systems thinking,
- industrial ecology,
- natural capitalism,
- performance economics,
- the blue economy, and
- regenerative design.

These schools of thought largely compare economies to ecosystems with an emphasis on natural and social capital. They describe an ideal economy as one that is resilient, regenerative, efficient and distributive. These attributes are based on the recognition that an economic system is dynamic and changing. Figure 2 illustrates some of the principles based on the CE schools of thought. The mechanisms to achieve these principles will be discussed in more detail to follow.

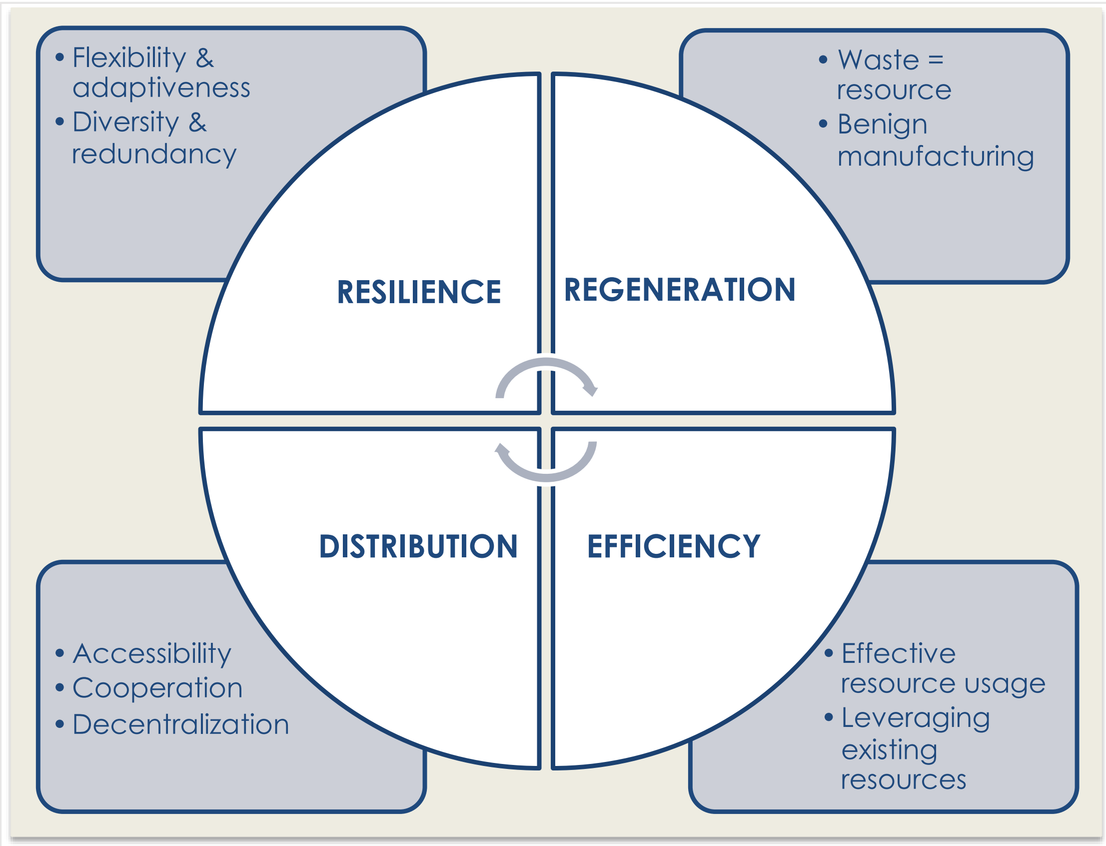

Figure 2: Circular Economy Principles

Resilience in an economy can be achieved through adaptations and responses to changes in the system via self-sustaining feedback loops. This requires constant assessment and evaluation of system functions and its stakeholders. Additionally, diversity and redundancy of system functions, as well as sources of revenue, can provide further resilience within a dynamic environment.

Regeneration is a fundamental feature of a secondary resource economy as it focuses on redefining waste as a resource, which is achieved through recycling and recovery activities. Another aspect of regeneration is ensuring that manufacturing activities are benign and do not negatively impact the environment. Industrial symbiosis is an example where these principles are utilised, whereby a waste or by-product of one process is the feedstock for another, thereby reducing or eliminating waste.

Efficiency is not a new feature in industrial development, the overall aim is to minimise resource use while still achieving the desired results. Mechanisms to achieve this include leveraging existing local expertise and readily available resource. An example of this in practice is the use of solar energy or other locally available renewable resources instead of fossil fuels. Another mechanism for efficient economies is providing services as opposed to products, as well as extending product life spans.

Distributive economies promote decentralised power, technology, wealth and knowledge service provision that is accessible to all. Examples of this are the opensource and peer-to-peer knowledge commons as opposed to intellectual property and privatised technologies. These mechanisms promote cooperation within economies.

2.1.2 The Waste Hierarchy

The Waste Hierarchy is another key contributor to waste management policy and practice today. It was developed by a Dutch science lecturer and parliamentarian, Ad Lansink, in the 1970s (Watson, 2013). This is around the same time the cradle-to-cradle vision was formed by Swiss architect, Walter Stahel (UNTHA UK, 2015).

The Waste Hierarchy provides a framework for preferential consideration of more sustainable waste management options. It is made up of five ranked options in order of desirability, namely prevention, reuse, recycle, recovery, and disposal (Watson, 2013). These are described in Table 1, including potential employment opportunities for these waste management practices, with reference to e-waste management.

Prevention involves interventions at the design and product manufacturing stages, as well as consumer awareness and behavioural changes. The employment opportunities for these interventions would, therefore, be associated with waste education and awareness campaigning, as well as product design.

Reuse, recycle, and recovery can be grouped into a broader category of value extraction options. Value extraction promotes the shift from managing e-waste as an environmental liability, or waste material, to managing e-waste as a resource (Bob et al., 2017). Value extraction interventions are also key elements of the CE model. These activities include collection and transportation logistics, as well as process development and implementation.

Lastly, disposal is the least desired waste management activity and should be considered as a last resort. Disposal involves landfilling which is usually done on a municipal level and provides employment opportunities for collection and transportation as well as landfill operation.

The drive towards zero waste to landfill initiatives, therefore, raises the concern that there might be job losses in the transport logistics and landfill operation. However, value extraction activities, such as recycling, has been proven to create more jobs with higher pay than that of landfill or incineration in Europe (EEA, 2011). Furthermore, landfilling would not be phased out completely or immediately, as there will still be residues in the form of material losses from value extraction processes.

In order to move away from treating waste as a liability, and move towards treating it as a resource, challenges such as legislation, consumer behaviours and investment into value extraction activities need to be overcome.

Table 1: The Waste Hierarchy (adapted from Godfrey, 2016)

Desirability	**Waste hierarchy activity**	**Description with reference to e-waste management activities**	**Employment opportunities**
Most desirable	**Prevention or reduction**	Using less hazardous material and more easily recyclable material in the design of devices. Reducing consumption of devices by: - Designing products with a long lifespan. - Using products until its end-of-life, when it is no longer in working condition (as opposed to end-of-use). - Donate to another user to extend the use of the device.	Sustainable consumption awareness campaigns; sustainable product design; donation schemes
	Reuse	Refurbishment: Testing, cleaning, and repairing whole devices or components for spare parts (usually for the same or similar application).	Collection, dismantling; refurbishing; sales
	Recycle	Processing and extraction of valuable materials such as plastics, glass and metals. Processing includes dismantling, sorting, value fraction separation and final product refining. Products from these processes will feed into manufacturing industries.	Collection; dismantling, sorting; refining; manufacturing; sales
	Recovery	Energy recovery, for example using organic materials as fuel for processing.	Waste-to-energy processing
Least desirable	**Disposal**	Landfilling, illegal dumping or incineration without energy recovery.	Landfill operation

2.1.3 The Secondary Resource Economy

Following on from the CE and Waste Hierarchy frameworks, are the concepts of a secondary resource economy and Urban Mining. Secondary resources largely refer to that which may be extracted from post-consumer waste. A flowsheet to describe a typical secondary resource economy is shown in Figure 3.

The supply of secondary resources depends on waste collection infrastructure from consumers, which would then be transported to waste processors through collection channels. Secondary resources are then recovered by recyclers for entry into the relevant manufacturing industries. The market for secondary resources is particularly important for the success of a secondary resource economy.

Urban mining is the collection of post-consumer waste for downstream value extraction or beneficiation activities. The comparison is made to traditional mining, where raw materials are extracted from urban minerals, that is, post-consumer waste, as opposed to mineral ores or other natural resources to continue the resource cycle.

For this research, the urban mineral ore of interest is WEEE, also known as e-waste. E-waste recycling for resource recovery can be used to reclaim energy and materials used to manufacture electrical and electronic products. The recovered value materials would then enter back into the manufacturing industry, not necessarily for electrical and electronic goods. This is done in order to strive towards a closed-loop flow of resources, thus contributing to the circular, secondary resource economy.

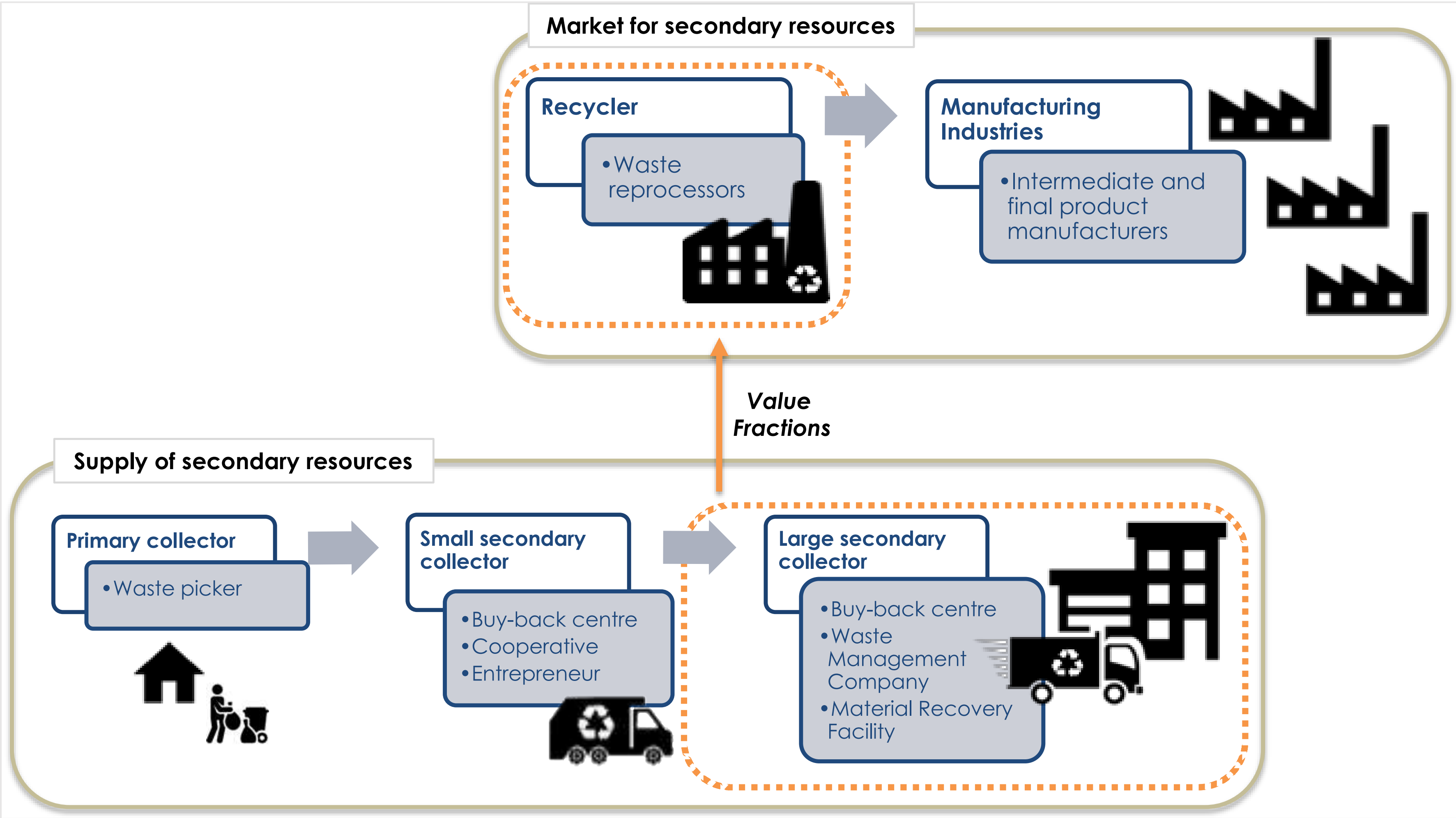

Figure 3: Secondary resource economy value chain (adapted from Godfrey, 2016)

2.2 E-waste – an Urban Mineral

E-waste as an urban mineral will be explored in the sections to follow in terms of its characterization and value chain activities. It is essential to define e-waste as well as identify the material composition of its diverse types and fractions. This informs the value chain activities and management system.

2.2.1 E-waste Definition & Classification

There is no universally accepted definition for e-waste, however there are a number of legal definitions such as that described in the European Union (EU) WEEE directive, which states that e-waste refers to "all components, sub-assemblies and consumables [of EEE] at the time of disposal" (Mmereki et al., 2016). Widmer & Lombard (2005) refers to it as any end-of-life electronic devices that no longer serves its purpose to its original owner. This definition includes the chance that the device may not have reached the end of its useful life, but it has reached the end of its life with the user. The StEP (Solving the E-waste Problem) initiative has a similar definition to this with an additional statement that the owner has no intention of re-using the device (StEP Initiative, 2014). E-waste thus refers to both end-of-life and end-of-use devices.

Many devices that end up in disposal streams are still in good working condition. This introduces the need for a testing and refurbishment step for resale and reuse of devices before dismantling and recycling to extend products' lifespans. Additionally, this provides a livelihood to small-scale refurbishers who resell such devices at affordable rates to the middle to low income earning customers who cannot afford to buy brand new devices.

E-waste is a diverse waste stream comprising of various types of devices with large variations in material composition, application, and size. Thus, it is important to classify e-waste into categories to allow for effective communication of material flow statistics, trade, pricing structures, and processing data. E-waste can be categorised in terms of application, material composition, average weight and sometimes average lifespan (Baldé et al., 2015), but there is currently no global consensus on e-waste categories.

In South African environmental legislation, e-waste is defined as an unclassified waste as it is listed under both general and hazardous wastes (GW18 and HW18) as per the National Environmental Management: Waste Act 59 of 2008 (NEMWA) (DEA, 2012).

The key differentiating factor between general and hazardous wastes according to the NEMWA is that general waste does not pose any immediate threat to human health or the environment. E-waste may be classified as general waste only if all the hazardous components have been removed (*NEMWA, No. 59 of 2008, Regulation,* 2012). Although the bulk of the material in e-waste is non-hazardous, depollution, or removal of hazardous components, is usually not conducted before being transported or processed.

Depollution is a difficult task given the complex design of devices, the composite materials used, and the variation in composition across types of devices. Furthermore, the hazardous components of e-waste are usually metallic fractions, which are the primary value fractions. Therefore, e-waste processing activities almost always involves e-waste containing hazardous components, and thus requires caution when it comes to its handling and disposal.

E-waste is broken down into sub-groups according to the application, size, and the handling and treatment thereof. For example, monitoring and control instruments usually contain radioactive elements which require specific procedures for safe handling. That being said, there is no correct method of classification as it depends on the purpose of the classification. E-waste categories can be used to communicate e-waste generation and recycling data, import and export customs codes, and in awareness communication (Baldé et al., 2015). Data on more specific and descriptive categories are ideal for planning and priority for different processing activities.

The comparison of the different e-waste categories is illustrated in Table 2. The e-waste categories listed in NEMWA are very similar to the old WEEE Directive except for further classification for toys, sport and leisure equipment, monitoring and control instruments, and automatic dispensers. However, the recast WEEE Directive was put into effect in 2012 to provide a non-ambiguous scope and legally account for any exclusions. The recast WEEE Directive collectively categorises healthcare, security, entertainment, and tools under small and large equipment. But it provides separate categories for temperature exchange equipment, and screens and monitors. The exclusions accounted for in the recast WEEE Directive include biologically contaminated medical devices, electric vehicles, and equipment solely designed for research and development purposes (Baldé et al., 2015).

Table 2: E-waste sub-groups as listed in the NEMWA, the original EU WEEE Directive and the recast EU WEEE Directive

NEMWA	EU WEEE Directive (original)	EU WEEE Directive (recast)
1. Large household appliances; 2. Small household appliances; 3. Office, information and communication equipment; 4. Entertainment and consumer electronics; 5. Lighting equipment; 6. Electric and electronic tools; 7. Security and health care equipment; and 8. Mixed WEEE.	1. Large household appliances; 2. Small household appliances; 3. IT and telecommunications equipment; 4. Consumer equipment and photovoltaic panels; 5. Lighting equipment; 6. Electrical and electronic tools (with the exception of large-scale stationary industrial tools); 7. Toys, leisure and sports equipment; 8. Medical devices (with the exception of all implanted and infected products); 9. Monitoring and control instruments; and 10. Automatic dispensers.	1. Temperature exchange equipment; 2. Screens and monitors; 3. Lamps; 4. Large equipment; 5. Small equipment; and 6. Small IT and telecommunication equipment with an external dimension of less than 50 cm.

It is important to note that batteries are listed as a separate classification to e-waste in SA (*NEMWA, No. 59 of 2008, Regulation,* 2012). The EU also has a separate Batteries Directive to regulate battery collection and disposal (European Commission, 2014a). Reasons for this are assumed to be that there is a wide variety of battery types and not all of them are found in e-waste devices. For example, lead-acid batteries are mainly used in motor vehicles and thus fall outside of the e-waste category. However, batteries such as lithium-ion or nickel-cadmium batteries are widely found in e-waste devices and would inevitably end up in the same waste stream as e-waste.

Most e-waste dismantlers and recyclers do not readily accept batteries. However, there are many take-back schemes available such as that offered by retailers including Woolworths and Pick 'n Pay. There have been feasibility studies done on both nickel-cadmium and lithium-ion batteries. The results showed that the recycling of these batteries is still not feasible in SA due to insufficient feedstock available to process at the necessary economies of scale. This proved similar to other e-waste streams, which is a direct result of poor collection infrastructure and network.

Arguably, batteries should be listed within the classification of e-waste as it often forms part of e-waste components. This would make sense in terms of the reporting of e-waste generation and recycling data. Batteries found in e-waste streams might remain legally undeclared and therefore, pose a risk of them being unaccounted for and possibly processed or disposed of alongside e-waste. This is important due to the difference in health and environmental risks as well as processing requirements for batteries compared to general e-waste devices.

2.2.2 E-waste Composition

E-waste devices contain a diversity of materials which include metals, plastics, glass among other chemical substances. Some of these can become hazardous to the environment and humans when discarded incorrectly. The material composition of e-waste is dependent on the type, manufacturer and age of the device. The major components of e-waste are PCBs, cables, device casings (metals and plastics), cathode ray tubes (CRT), liquid crystal displays (LCD), batteries, storage devices, motors, and heat exchangers. Given the diversity of the waste stream, it has been notoriously difficult to determine an accurate breakdown of the material composition. However, most studies usually present five main categories namely, ferrous metals, non-ferrous metals, glass, plastics and PCBs (Widmer et al., 2005).

The material composition of two typical e-waste streams is presented in E-waste also contains hazardous components which include flame retardants found in plastic-metal mixtures, chlorofluorocarbons (CFCs) found in cooling units and insulation foam, and radioactive elements found in industrial processing equipment. Trace heavy metals such as lead, cadmium and mercury, found in batteries, lighting, PCBs, CRT monitors and telecommunication sheathing also form part of hazardous e-waste components (Cui & Forssberg, 2003; Ecroignard, 2006; Mahesh et al., 2016). However, most of these materials are being phased out and replaced with less toxic materials. Knowledge of the presence of hazardous components are essential for e-waste recyclers due to the risk of exposure and/or release upon processing.

Table 3. The metal content of e-waste makes up approximately 60 wt.%, with the largest fraction being iron and steel. Precious metals are mainly found in PCBs - which makes up between 1-3 wt.% of e-waste. The precious metal composition of PCBs will be discussed in Section 2.2.2.1. The non-metal elements of e-waste streams include various plastics, glass, ceramics, wood and rubber. The plastics content makes up about 15-20 wt.%.

E-waste also contains hazardous components which include flame retardants found in plastic-metal mixtures, chlorofluorocarbons (CFCs) found in cooling units and insulation foam, and radioactive elements found in industrial processing equipment. Trace heavy metals such as lead, cadmium and mercury, found in batteries, lighting, PCBs, CRT monitors and telecommunication sheathing also form part of hazardous e-waste components (Cui & Forssberg, 2003; Ecroignard, 2006; Mahesh et al., 2016). However, most of these materials are being phased out and replaced with less toxic materials. Knowledge of the presence of hazardous components are essential for e-waste recyclers due to the risk of exposure and/or release upon processing.

Table 3: Material composition of typical e-waste streams

Material	**Composition (Wt.%)** (Wilkinson et al., 2001)	**Composition (Wt.%)** (Widmer et al., 2005)
Iron & Steel	47.9	-
Copper	7.0	-
Aluminium	4.7	-
Other non-ferrous metals	1.0	-
Total Metals	**60.6**	**60.2**
Plastics (No flame retardants)	15.3	-
Plastics containing flame retardants	5.3	-
Total Plastics	**20.6**	**15.2**
PCBs	**3.1**	**1.7**
Screens	-	11.9
Cables	-	2.0
Metal-plastic mixture	-	5.0
Glass	5.4	-
Wood & Plywood	2.6	-
Ceramics	2.0	-

Rubber	0.9	-
Pollutants	-	2.7
Other	*4.8*	*1.4*

CRT monitors are made up of glass containing lead. They are not currently recycled in SA, even though there are available recycling solutions (Vidyadhar, 2016). CRT monitors are therefore sent for disposal in hazardous landfills.

The material composition of electrical and electronic devices is not only diverse but is constantly changing as technology advances. Devices are becoming more compact, less toxic materials are being used, and the overall design is more complex which makes material recovery more complex. The material value of these devices is thus changing, in terms of the quantity and recyclability of recovered materials. These factors will be discussed in more detail for three of the main value fractions namely, PCBs, fluorescent lamps and plastics.

2.2.2.1 Printed Circuit Boards

PCBs are an integral component of all electrical and electronic devices, both for functionality as well as economic potential of its metal content, which makes up to 30 wt.% of the PCBs (Li et al., 2007). The value held in the metal fraction found in PCBs is highlighted as a promising source of secondary metal supply, particularly for critical and strategic high-value metals (UNEP, 2013).

The design, structure and composition of PCBs vary with age, application and manufacturer (Zhang et al., 2012). Due to the diverse and complex nature of waste PCBs, characterisation is necessary to establish value and a suitable route for processing (Hadi et al., 2015).

All PCBs consist of three main components, namely, a non-conducting substrate or laminate – usually fibreglass, a conducting substrate – the copper layer(s), and the electronic components attached to the substrate (Hadi et al., 2015). PCBs can be single, double or multi-layered, of which multi-layered is the most common. They are further categorized into various grades depending on their precious metal content.

The material composition of metals in PCBs from various devices is listed in Table 4. Non-metal elements, making up the remainder of the weight, are however not listed in the table; these include fibreglass (glass fibre-reinforced plastic), other plastics and ceramics. The main metals of concern include the base metals, Fe, Al, Cu, and precious metals, Ag, Au, and Pd (Hagelüken, 2006a). Other metals not included in Table 4 are Sn, Pb and Ni, which is used as a surface finish to protect the copper tracks as well as to provide a suitable surface for soldering (Wright, n.d.). As illustrated in Table 4, the material composition of PCBs can vary considerably from device to device. However, the order of magnitude of the listed values is generally consistent (Hagelüken, 2006a).

By weight, the precious metal content may appear to be negligible, but it is of much higher monetary value than the base metals even at these low concentrations. The value share of precious metals far outweighs that of the base metals for PCBs from PCs, mobile phones, and calculators. While, copper is a significant value share contributor in PCBs from TVs, portable audio players, and DVD players.

Table 4: Material composition and value share of printed circuit boards from various devices (reproduced from Hagelüken, 2006)

Material Composition	**Fe (Wt.%)**	**Al (Wt.%)**	**Cu (Wt.%)**	**Ag (ppm)**	**Au (ppm)**	**Pd (ppm)**
Mobile phone	5%	1%	13%	1380	**350**	210
PC	7%	5%	20%	1000	**250**	110
Calculator	4%	5%	3%	260	**50**	5
TV	28%	10%	10%	280	20	10
DVD player	62%	2%	5%	115	15	4
Portable audio player	23%	1%	21%	150	10	4
Value Share	**Fe**	**Al**	**Cu**	**Ag**	**Au**	**Pd**
Mobile phone	0%	0%	7%	5%	**67%**	21%
PC	0%	1%	14%	5%	**65%**	15%
Calculator	0%	5%	11%	7%	**73%**	4%
TV	4%	11%	**42%**	8%	27%	8%
DVD player	13%	4%	**36%**	5%	37%	5%
Portable audio player	3%	1%	**77%**	4%	13%	3%

Table 5 illustrates the gold content of different PCB grades, starting from gold concentrations of 0-50 g/ton for very low grade, up to 400+ g/ton for very high grade. Based on the gold content for PCBs from various sources in Table 4, it can be deduced that PCBs from PCs and mobile phones are generally high-grade boards, while those from a TV, DVD player, portable audio player, or calculator are low-grade.

Table 5: Gold content for different grades of PCBs and typical gold ore

	Gold (Wt.%)	Gold (g/ton)	Source
Very low grade	0-0.005	0-50	(Salway, 2011)
Low grade	0.005-0.01	50-100	
Medium grade	0.01-0.02	100-200	
High grade	0.02-0.04	200-300	
Very high grade	0.04+	400+	
Gold ore	0.0001-0.001	1-10	(Tuncuk et al., 2012)

Gold ore is considered to be very low grade, with concentrations between 1-10 g/ton of ore. Therefore, the gold concentration of higher grade PCBs can be up to four hundred times the concentration found in gold ores (Tuncuk et al., 2012; Hadi et al., 2015). Furthermore, the copper content in PCBs can be up to 40 times that found in typical copper ores (usually 0.5-1wt.% Cu). This is one of the main economic motivations for developing and investing in processes for extracting metals from e-waste, and more specifically waste PCBs.

2.2.2.2 Fluorescent lamps

Fluorescent lamps consist of mostly glass, metal and plastic fittings, phosphor powders and mercury (Binnemans & Jones, 2014). The typical material composition of a compact fluorescent lamp is listed in Table 6.

Table 6: Typical material composition of fluorescent lamps (Binnemans & Jones, 2014)

Material		Wt.%
Glass		88
Metals		5
Plastics		4
Phosphor powder	Halophosphate phosphor	1.35
	Silica	0.6-0.9
	Alumina	0.36
	Rare earth phosphors	0.3-0.6

	Residue	0.15
Mercury		0.005

The recovery of rare earth elements from the phosphor powders is the main value attraction for lamps, while mercury is the main hazardous fraction considered for depollution activities.

2.2.2.3 Plastics

Plastics are the second-largest component in e-waste, making up about 20-30 wt.% depending on the category (Mahesh et al., 2016). Most plastic types are recyclable in their uncontaminated form, however, plastics used in devices in recent times are often mixed composites and/or contain contaminants such as halogenated flame retardants which causes technical challenges in the downstream recycling processes. There are several different types of plastic polymers used in Electronic and Electrical Equipment (EEE) for various applications. A few of these are listed in Table 7. Plastic applications range from device housing or casing, cable insulation and sheathing, as well as component casing.

Some of these plastics contain toxic substances which makes them hazardous and unsuitable to recycle. The hazardous additives referred to here are mainly Brominated Flame Retardants (BFR) as well as heavy metals (Mahesh et al., 2016). Therefore, it becomes important to rigorously sort plastics before choosing their respective processing routes. This is sometimes difficult due to the absence of correct labelling according to plastic-type and any additives present, particularly if they are hazardous. It is difficult to visually differentiate between plastic polymer types as well as those with or without additives, especially those used for the same application; for example Acrylonitrile butadiene styrene (ABS), High Impact Polystyrene (HIPS) and Polycarbonate (PC) are all used for device casings (Mahesh et al., 2016).

Due to the variety of materials and complexity of their assembly, the material characterisation of e-waste and its components is an important step. This informs the sorting process, thus preparing e-waste fractions for their respective recycling routes within the value chain.

Table 7: Typical applications of plastic polymers in electrical and electronic devices (European Commission, 2011)

Polymer	Application
Acrylonitrile butadiene styrene, ABS	Housings for phones, small household appliances and monitors; enclosures of internal parts of Information and Communication Technology (ICT) devices
High Impact Polystyrene, HIPS	Housings for small household appliances and consumer electronics
Polycarbonate, PC	Housings of ICT devices, household appliances and lighting
Epoxy resin	PCBs
Polypropylene, PP	Internal electronic components; housings for small household appliances
Poly p-phenylene oxide, PPO	Housings and components for consumer electronics, and some small household appliances
PC/ABS	Housings for ICT equipment and some small household appliances
Polyurethane (foam)	Insulation for refrigerators, dishwashers
Polyvinyl chloride (PVC)	Cable sheathing
Polyethylene (PE)	Cable insulation and sheathing

2.2.3 The E-waste Value Chain

E-waste value chain, or beneficiation, activities are focused around metal extraction and refining. Exploring the parallels formed with the minerals beneficiation chain through the concept of the urban mine is particularly interesting for SA where the economy is based on the minerals extraction industry. The mining of Platinum Group Metals (PGMs) and gold in SA – also present in e-waste – makes the comparison all the more suitable.

The minerals beneficiation chain, illustrated in Figure 4, generally follows the sequence: exploration and mining of ores, followed by concentrating the mineral content (crushing, screening, milling, flotation) and separating it from the gangue materials. Thereafter product refining takes place to produce metal products, which then enter a manufacturing process to produce and sell new products.

The e-waste value chain, shown in Figure 5, follows a similar sequence, where exploration and mining equate to collection and storage of e-waste. This is followed by dismantling and sorting, as well as the pre-processing stages, which form parallels with the concentrating stage in the minerals beneficiation chain. Thereafter the product refining or end-processing stages follow, which feed into a manufacturing sector for production and sale of new products. Refurbishment is also found in the e-waste beneficiation chain, in which components or whole devices are prepared for resale and reuse, introducing a supplementary revenue generator.

The initial stages of both the minerals beneficiation and e-waste value chains form part of an extractive economy, as illustrated in Figure 4 and Figure 5, while manufacturing and sales form part of an industrial economy.

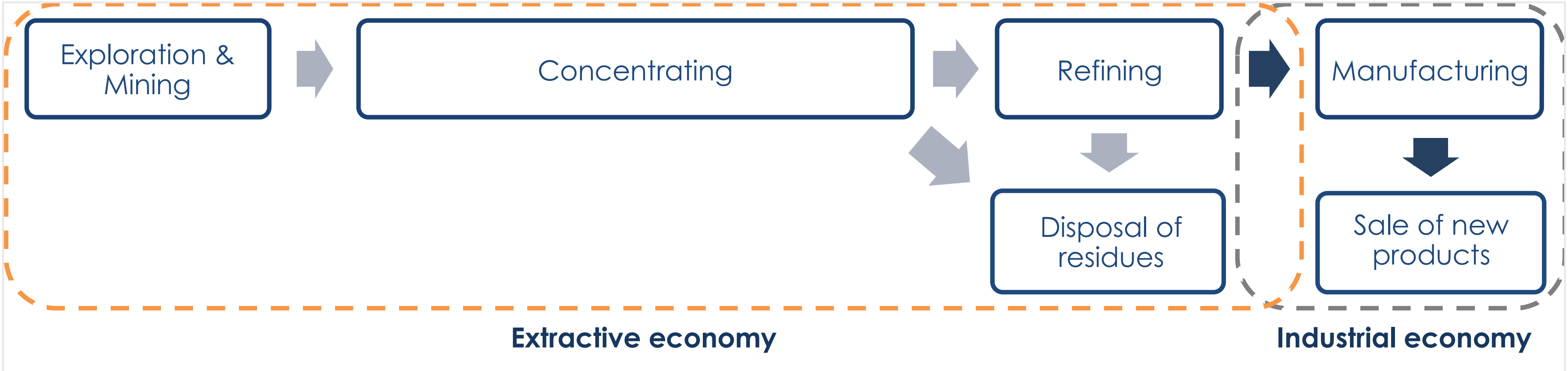

Figure 4: Minerals beneficiation chain (adapted from Mungoshi, 2011)

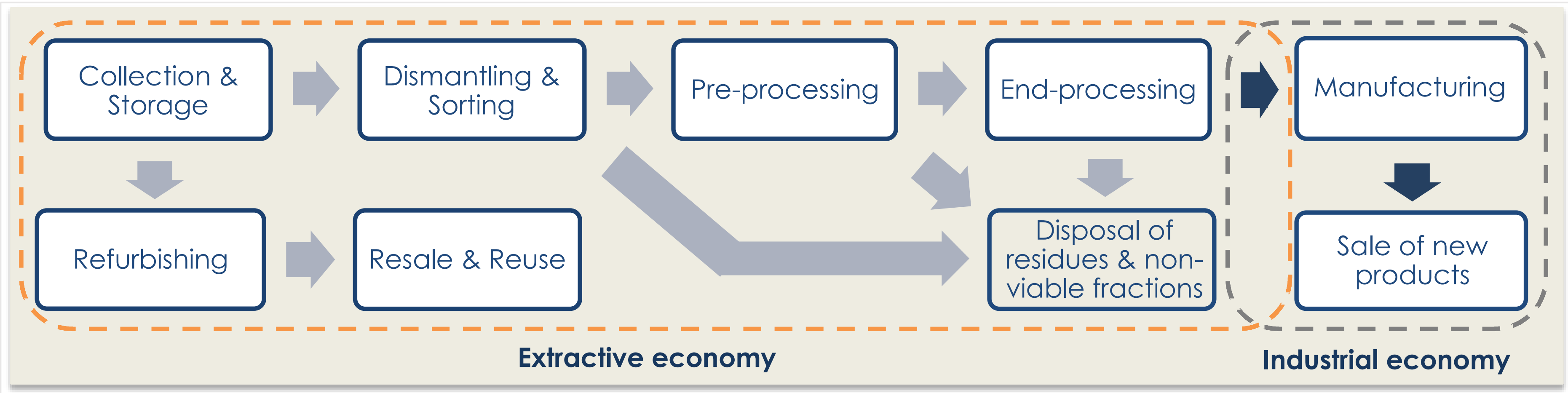

Figure 5: E-waste value (beneficiation) chain

Generally, resource-rich countries would form extractive economies, operating along the initial stages of the beneficiation chain. The concentrated and/or refined products would then be exported to industrial economies, where manufacturing of new products would take place. An example of this phenomenon can be seen in the PGM industry in SA.

PGM ores were historically mined and concentrated locally, while the concentrate was exported for further refining and end-use of the metals. However, in the 1970s, SA started to embark on refining locally and exporting the platinum (Pt) metal. Later, some end-manufacturing of auto-catalysts developed locally, but never to absorb significant portions of the PGM products (Dewar, 2012). Exports of PGMs in SA accounted for 88.5% of the total sales in 2016 (Chamber of Mines of South Africa, 2017), illustrating that SA remains an extractive economy in terms of its PGM industry. This is a result of the attractive financial gains in international markets, making local refining and manufacturing subject to competitively high prices and thus economically unattractive (Stilwell, 2004; Turok, 2013).

A similar tendency can be observed in the local e-waste recycling industry. E-waste is collected, manually dismantled and sorted; the metal-rich streams are then prepared for export, thereby forming a predominantly extractive e-waste recycling economy. However, the challenges facing the e-waste industry is different to that of the PGM industry. The local PGM industry has access to large volumes, but subject to competition with the international markets. While the e-waste industry faces limited access to sufficient e-waste volumes to make pre- and end-processing economically feasible (Lydall, Nyanjowa & James, 2017). In other words, there are not enough urban mines to provide the necessary volumes of feed.

PGM mining is well established in SA, while e-waste mining, that is, the collection infrastructure, is underdeveloped. The lack of formal take-back schemes, lack of consumer recycling awareness, as well as e-waste in storage or ending up in landfills, all result in the inaccessibility of existing e-waste volumes (Finlay, 2005). SA's e-waste recycling industry thus remains small-scale in operation and capacity compared to industrial European recyclers. Economies of scale is thus a key factor when considering end-processing activities.

There is a definite push for local value-adding and beneficiation for minerals and metals in SA, as outlined in the country's beneficiation strategy (Department of Mineral Resources [DMR], 2011). The intention is to enhance industrialisation in the country, which involves economic and infrastructure development, job creation and to address income inequality. The strategy for PGMs is focused on developing the autocatalytic industry as well as jewellery fabrication (DMR, 2011).

In order to transition towards a secondary resource economy and industrial economy, SA needs to invest in e-waste end-processing technologies as well as the formation of a local manufacturing industry to utilise the products. These should take place simultaneously, in order for one to stimulate the growth of the other. If importance is only placed on collection infrastructure, then SA is at risk of remaining an extractive economy for e-waste. While, if the manufacturing is the main focus, then there is a risk of not having enough feedstock, as well as perpetuating a poor waste management system. Thus e-waste industry development provides an advantage to both waste management and metal product manufacturing industries.

E-waste end-processing technologies will be explored in the following section, with consideration of economies of scale as well as other contextual factors relevant to SA.

2.3 E-waste Processing Technologies

The main economic driver for e-waste processing is the metallic fraction, most of which is concentrated in the PCBs and its components. Therefore processing technologies are focused on extracting metals from PCBs. A schematic of the potential flow routes is illustrated in Figure 6 (Tuncuk et al., 2012).

Initially, a pre-treatment stage occurs to concentrate the metal fractions, which may include manual dismantling and sorting of the larger components, as well as size reduction., followed by further physical separation processes. Size reduction helps liberate mixed materials in preparation for physical separation processes (Ilankoon et al., 2018), however, the cost implication of the energy requirements for size reduction is an important consideration for its feasibility.

Physical separation processes make use of differences in the physical properties of materials, particularly that of metal and non-metal fractions. These processes include eddy current, gravitational, magnetic and electrostatic separation. The non-metal fraction consisting of plastics, glass, and wood, while the metal fraction is largely ferrous metals. The metal-rich fraction then undergoes further separation through one of two major routes for metal extraction, namely pyrometallurgy and hydrometallurgy. This is followed by electro-metallurgical processes for final product refining to produce individual base and precious metal streams (Tuncuk et al., 2012).

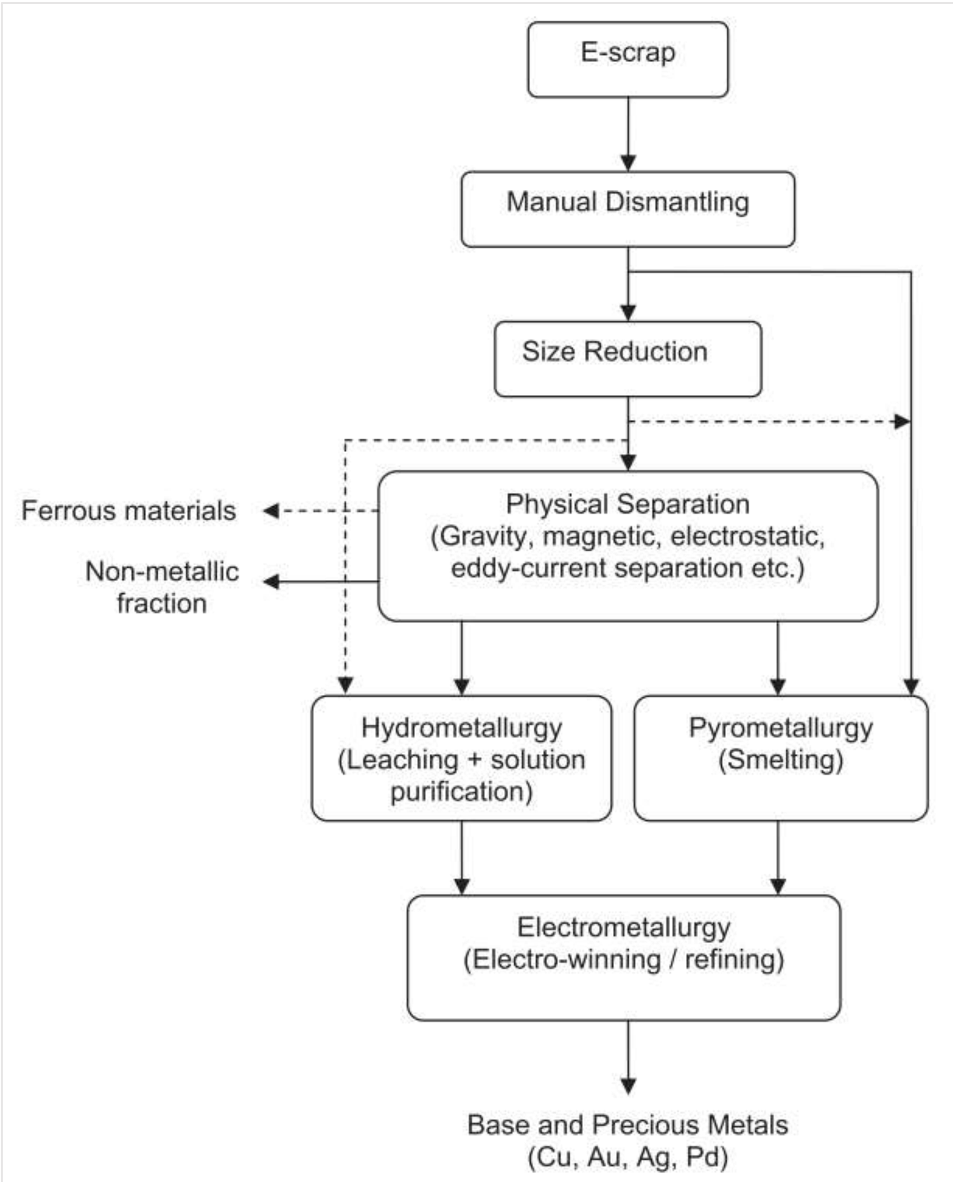

Figure 6: Schematic of potential process flow routes for metal extraction from e-waste (Tuncuk et al., 2012)

2.3.1 Pre-processing

Dismantling is the first stage in separating material fractions in the e-waste value chain. Manual dismantling is largely used in SA due to the low labour costs compared to developed countries who use mechanical dismantling. Manual dismantling contributes to job creation, is less energy-intensive and provides better quality fractions when compared to mechanical dismantling (Wang et al., 2012; Bocken et al., 2016; Lydall, Nyanjowa & James, 2017).

Manual dismantling involves disassembly of e-waste devices using hand tools such as hammers, screwdrivers, pliers, drills, grinders, scissors and cutters. Some of these tools require electricity. Other dismantling processes include solder removal, specifically for removing components from PCBs.

The purpose of pre-processing includes preparation for transport, material liberation and separation. Pre-processing activities include size reduction, densification, compacting and separation. These activities can be divided into two stages for e-waste pre-processors. The first, elementary stage includes size reduction and compacting for transport. The second, advanced stage includes size reduction, compacting and further separation processes to separate metal and non-metal fractions, as well as organic and non-organic fractions. A list of the equipment used in the pre-processing stage of the value chain is presented in Table 8.

Table 8: List of equipment used for various applications in the pre-processing stage

<table>
<tr><th>Application</th><th>Equipment used</th><th colspan="2">Type of processors</th></tr>
<tr><td>Size reduction and densifying materials</td><td>Shredders, mills, hammers, grinders, pulverisers, shears, granulators</td><td rowspan="2">Elementary, first-stage e-waste pre-processors</td><td rowspan="3">Advanced, second-stage e-waste pre-processors</td></tr>
<tr><td>Compacting materials (for ease of transport)</td><td>Balers (large pieces of metals and plastics), briquetting machines (small pieces)</td></tr>
<tr><td>Separate metallic and non-metallic fractions</td><td>Dense media separators, rotatory magnets, eddy current separators, cyclones, granulators</td><td></td></tr>
</table>

Separate organic from non-organic fractions	Water separation tables		
Purify airstreams	Scrubber		
Lamp crushing, separating and cleaning	Lamp recycling systems, special designs such as Mercury Recovery Technology (MRT) (Sweden) or Balkan (UK)	Lamp recyclers	

Degassing facilities for temperature exchange equipment such as fridges are rare in SA, only one large recycler has a degassing pump (Lydall, Nyanjowa & James, 2017). Other recyclers only accept already degassed equipment. This inevitably means that there is an uncontrolled release of refrigerants into the atmosphere taking place off-site.

Pre-processing recyclers in SA are currently not operating under full capacity due to limited available volumes, which is also true for lamp recyclers. This illustrates that there is no space for new entrants providing additional capacity as there would be no supply at the current collection and recycling rates.

2.3.2 Pyrometallurgical processing

Pyrometallurgy is based on the thermo-physical separation of the metal and non-metal phases, which requires high energy input. This is typically achieved through copper smelting followed by electro-refining and precious metal refining. Major smelting operations for e-waste metal fractions include Umicore in Belgium, Boliden in Sweden, Noranda in Canada. These process flowsheets are presented and reviewed extensively in literature (Cui & Zhang, 2008; Sahin et al., 2015; Vidyadhar, 2016; Ilankoon et al., 2018).

The process flowsheet for the Umicore smelting operation is illustrated in Figure 7. This integrated smelter-refinery can treat up to 350 000 tons/per annum of feedstock, which includes precious metal-bearing mixed secondary materials (Hagelüken & Corti, 2010).

The metal-rich e-waste fraction is co-processed with a mixed secondary metal stream which enters into a copper smelter to produce copper bullion containing precious metals and slag. The organic compounds (mainly plastics) get incinerated and used as an additional fuel source or oxidation agent. The copper bullion is then sent for electro-refining to produce copper metal and precious metals in the anode slimes. The precious metals stream then goes to the precious metal refinery for further separation into its metal components, including silver, gold, PGMs including platinum, palladium, rhodium, iridium and ruthenium (Au, Ag, Pt, Pd, Rh, Ir, and Ru) (Hagelüken, 2006b).

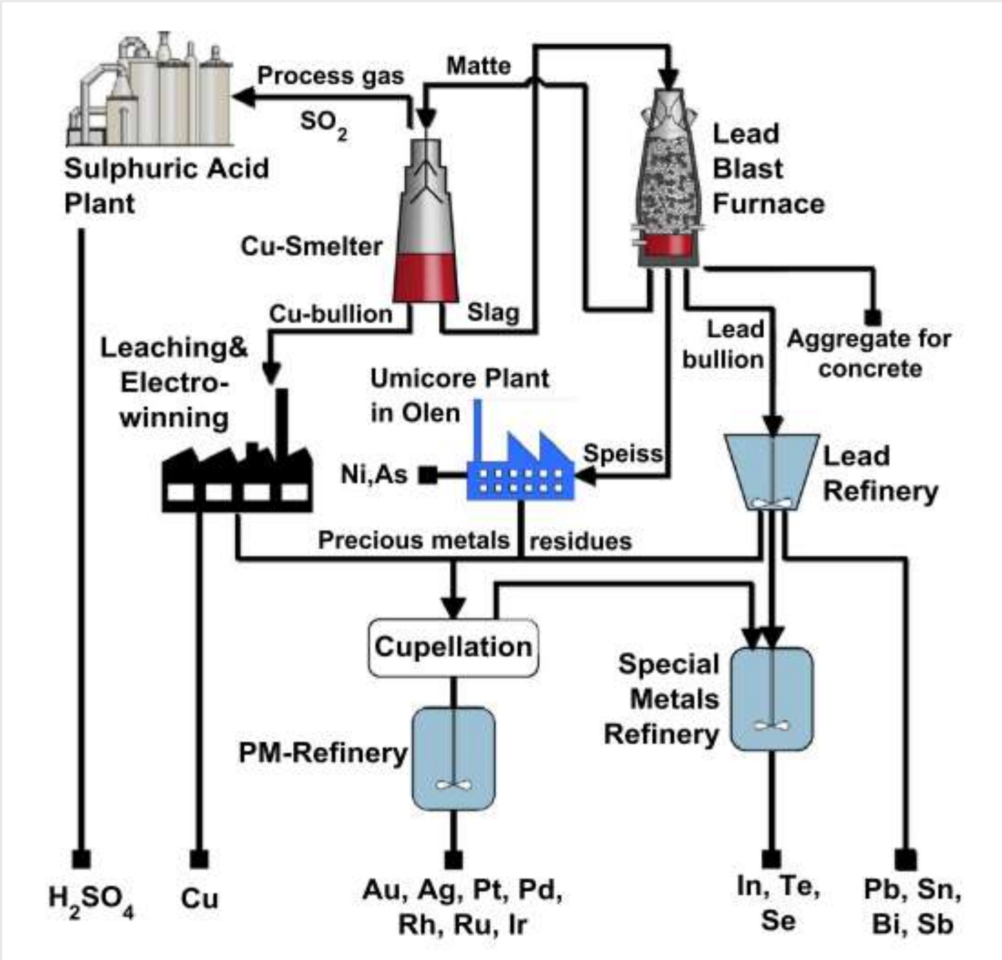

Figure 7: Process flowsheet for Umicore's base and precious metals extraction from mixed metal wastes (As presented in Tuncuk et al., 2012, reproduced from Hagelüken & Corti, 2010)

The slag from the main smelter gets processed in the lead blast furnace to produce lead bullion, copper matte, nickel speiss and depleted slag (used as aggregate for concrete). The copper matte gets sent back to the main smelter, while the nickel speiss is leached to produce nickel sulphate. The lead bullion is sent to the lead refinery, which produces lead, tin, antimony and bismuth (Pb, Sn, Sb, and Bi), as well as a residue which gets further processed in the special metals refinery to produce indium, selenium and tellurium (In, Se and Te) (Hagelüken, 2006b).

The gas emissions from the copper smelter are high in sulphur dioxide, which gets further processed to produce sulphuric acid. If the organic material present in the feedstock contains halogens from flame retardants, toxic gases such as dioxins and furans are produced. However, special installations exist in Umicore's operations to monitor and prevent the formation of these gases (Hagelüken, 2006b).

Pyrometallurgy has additional disadvantages in that processes based on it require large capital investment and large volumes of feed with high metal content (Cu and precious metals) in order for it to be energy efficient (Tuncuk et al., 2012).

2.3.3 Hydrometallurgical processing

Hydrometallurgical processing usually requires size reduction in the pre-treatment stage to assist in liberating metals from non-metal fractions such as plastics or fibreglass. Size reduction, therefore, increases the contactable metal surface area and accessibility to the lixiviant.

Oxidative leaching is required for the extraction of base and precious metals. The pregnant leach solution(s) is then filtered for solid-liquid separation and purified via precipitation of impurities, solvent extraction, ion exchange or adsorption. Further processing is then required for the recovery of pure metals (Tuncuk et al., 2012; Akcil et al., 2015).

For the extraction of multiple metals, a single-stage leach or multi-stage sequential leach can be performed. The choice of lixiviant and type of leach system (single- or multi-stage) usually involves considerations such as recovery and selectivity of target metals, cost and availability of leaching agent, rate of leaching, chemical stability of leaching solution, and the toxicity of the leaching agent (Cui & Zhang, 2008; Tuncuk et al., 2012; Akcil et al., 2015; Ilankoon et al., 2018).

For copper extraction from PCBs, acid leaching in the presence of an oxidant is usually performed as the first leaching stage (Behnamfard, Salarirad & Veglio, 2013). Various mineral acids have been researched such as HCl, H_2SO_4, HNO_3, $HClO_4$, NaClO.

Hydrogen peroxide (H_2O_2) is a strong oxidant commonly used in conjunction with acids such as HNO_3 and H_2SO_4. The concentration of the oxidant and the temperature of the process are the most important factors affecting metal recovery (Tuncuk et al., 2012).

Alternatively, oxidative ammonia leaching or bio-leaching has also been used for copper extraction. Bioleaching of metals from e-waste is mainly performed using iron-oxidizing strains of acidophilic bacteria which readily oxidise the ferrous ion (Fe^{2+}) to generate ferric ion (Fe^{3+}). Ferric ion is a powerful oxidising agent for metals such as copper, and therefore promotes its dissolution. A well-controlled acid environment is necessary for bioleaching systems to keep metals in solution. Sulphuric acid is commonly used, therefore precious metals and lead are found in the PCB residue as they do not dissolve in the sulphate medium (Tuncuk et al., 2012).

For precious metal extraction, lixiviants such as cyanide, halides, thiourea and thiosulfate have been used, particularly for their ability to form stable gold complexes. (Tuncuk et al., 2012). Akcil et al. (2015) provide an extensive review of the aforementioned lixiviants for precious metal recovery. Aqua regia has also been used for gold extraction, together with copper extraction, however, silver and palladium remained in the solid residue (Tuncuk et al., 2012).

An example of a hydrometallurgical flowsheet is illustrated in Figure 8 (Kamberović, Korać & Ranitović, 2011). After pre-treatment of PCBs to remove the non-metal fractions as well as iron and aluminium, the PCBs undergo a two-stage leaching process. The first of which is a sulphuric acid and hydrogen peroxide system to extract copper. Followed by a thiourea leach system in the presence of sulphuric acid and ferric ion, to extract silver and gold. The copper-rich solution undergoes cementation to remove silver cement followed by electro-winning to extract copper. The remaining solution then undergoes another cementation process to extract zinc and remove iron and nickel cement.

The thiourea leach solution gets filtered to remove lead and tin solder, and then undergoes cementation to remove silver and gold cement. The remaining solution undergoes a sodium hydroxide neutralisation stage to remove zinc sulphate sludge for further refining in the zinc smelter.

Hydrometallurgical processes are favoured for its high metal recoveries, as well as its suitability for small-scale processing. Other benefits include low capital costs and low hazardous emissions when compared to pyrometallurgical processes (Tuncuk et al., 2012; Akcil et al., 2015). However, hydrometallurgical processes produce large acid waste streams which would require appropriate wastewater management systems. Furthermore, hydrometallurgical plants have mainly been researched on the lab or pilot scale for metal extraction from e-waste, however, the feasibility for commercial or industrial scale systems have yet to be investigated (Ilankoon et al., 2018).

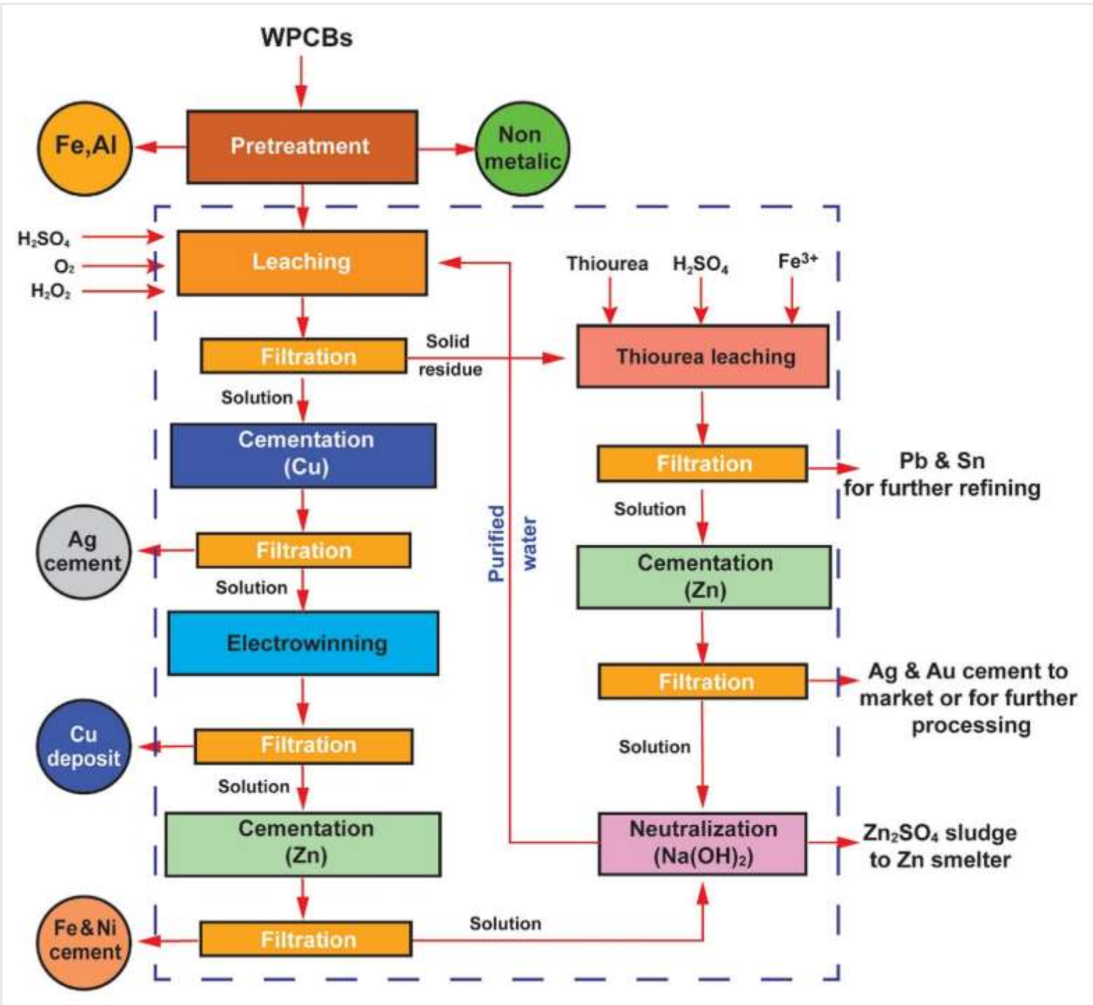

Figure 8: Example of a Hydrometallurgical Process for Base and Precious Metal Extraction from PCBs (As presented in Ilankoon et al., 2018, reproduced from Kamberovic, Korac & Ranitovic, 2011)

Another prospect to consider for hydrometallurgy is the possibility to design portable or mobile systems, which may be ideal for accessibility and decentralised facilities for small-scale use (Kamberović, Korać & Ranitović, 2011; Innocenzi, De Michelis & Vegliò, 2017). Furthermore, modular systems are also of great interest due to the variability in the composition of feed streams.

2.3.4 Informal E-waste Processing

Informal e-waste processing involves unregulated operations that use crude recycling techniques such as manual dismantling and open burning of e-waste components to separate metal and non-metal fractions. Backyard operations of acid leaching (aqua regia, nitric acid, sulphuric acid) have also been used to extract copper and gold from PCBs (Manhart, 2011; Ongondo, Williams & Cherrett, 2011; Ilankoon et al., 2018). Informal recycling is usually associated with illegal dumping of non-viable fractions and residues. The health and safety hazards prevalent at these informal sites are of great concern.

China has been well-known for its informal e-waste sector, particularly in Guiyu in Guangdong province, using the methods described above. The resulting consequences include contamination of drinking water sources and soil, emissions of toxic gases during open burning. Several serious health issues have been reported as a result (Huang, Guo & Xu, 2009; Ongondo, Williams & Cherrett, 2011).

2.3.5 Choice of Metal Extraction Technology

The choice of metal extraction technology for e-waste recycling is usually a debate between hydrometallurgy and pyrometallurgy. The argument is that large-scale smelting is not the most environmentally sound end-processing technology for metal extraction. This is due to the large volumes of toxic emissions produced which require sophisticated treatment systems only possible with the relevant financial and technology investment. Whereas, hydrometallurgical or bio-hydrometallurgical processing routes is argued to be less hazardous (Cui & Zhang, 2008; Tuncuk et al., 2012; Akcil et al., 2015). However, hydrometallurgical processes are criticised for generating large volumes of acidic wastewater which require further processing. Despite this, hydrometallurgy has merit in the context of developing countries where it is more suitable for smaller-scale processing.

Furthermore, hydrometallurgy is used for the final product refining stages after both hydrometallurgical and pyrometallurgical metal extraction, which makes the debate futile (Ilankoon et al., 2018). Nevertheless, there is no comprehensive comparison between the two technologies which offer very different benefits depending on the context. The basis for this comparison should not be one-dimensional, but rather it requires an economic feasibility analysis, exergy and energy analysis, and waste management consideration to make a fair judgement (Reuter & Wills, 2013; Ilankoon et al., 2018). Further consideration should be given to contextual constraints such as the scale of operation required, quality of feedstock, location and accessibility of the facility, as well as the relevant regulations.

Comprehension of e-waste management scenarios and contextual factors is key in choosing or adapting existing technologies for a particular context. The next section presents scenarios and global systems of e-waste management.

2.4 E-waste Management Scenarios

The UNEP reported four main e-waste disposal scenarios in the Global E-waste Monitor Reports (Baldé et al., 2015; Baldé et al., 2017). These scenarios are as follows.

Scenario 1: Official Take-back Systems – based on legal systems such as extended producer responsibility (EPR) schemes for the EEE industry. These collection schemes can be implemented by municipalities, retailers and private companies.

Scenario 2: Disposal of E-waste in Mixed Residual Waste – where there is limited or no separation-at-source system for waste generators, which results in e-waste being mixed with household or general waste. E-waste thus ends up in the municipal waste disposal system which may be landfills or incineration plants depending on the location.

Scenario 3: Collection of E-waste Outside Official Take-back Systems in Developed Countries – this scenario is based on systems where e-waste is collected and exported as second-hand goods for reuse in developing countries. However, the Basel Convention ensures that this trade can only occur if both parties are in agreement.

Scenario 4: Informal Collection & Recycling in Developing Countries – this scenario is based on the informal e-waste recycling sector mainly prevalent in developing countries such as Ghana, Nigeria, as well as parts of India and China (Baldé et al., 2015). These countries have large second-hand goods markets and were historically victim to 'e-waste dumping' disguised as second-hand goods trade. The e-waste that cannot be reused enters an informal dismantling and processing system using crude methods such as open burning and unregulated acid leaching for metals recovery as discussed in Section 2.3.4.

It should be noted that while these scenarios do occur or have taken place in the past, this scenario analysis has a limited view. E-waste systems in developed and developing countries cannot be grouped into just one of these scenarios. These scenarios often occur in conjunction with one another with added complexity. This is the case in many countries, including SA as seen in several studies (Widmer & Lombard, 2005; Bondolfi, 2007; Finlay & Liechti, 2008).

2.4.1 The Best of Two Worlds Philosophy

As mentioned in the previous section, most e-waste value fractions in SA are exported for further refining in developed countries. This is not only the case in SA but in other developing and emerging, economies as well, such as India. This so-called 'international collaboration' is promoted in the Best-of-2-Worlds (Bo2W) theory by Wang et al., (2012). The basic theory is to leverage the developing world to perform the manual dismantling and sorting stages of the value chain. These countries would then pass on the high-quality value fractions to the developed world who perform the more technology-intensive end-processing stages. The overview of the Bo2W philosophy is illustrated in Figure 9.

The rationale behind the Bo2W theory is twofold, the first being that manual dismantling is preferred over mechanical dismantling due to better material separation and liberation. However, manual dismantling has intensive low-skilled labour requirements, which is more suitable for the developing world context given the low labour costs and the large population of unemployed, low skilled workers. Furthermore, this avoids the high energy requirements and costs of mechanical dismantling available in the developed world (Wang et al., 2012; Bocken et al., 2016).

Secondly, the end-processing stages are more dependent on technology investment and require special health and safety precautions, specifically in reference to high-temperature smelting and metal refining processes. This stage is argued to be more suitable for developed countries where technology, financial investment, high skilled labour and strict health and safety regulations are widely accessible. This also avoids the informal and crude processing that may take place in developing counties which poses serious health and environmental risks (Wang et al., 2012; Bocken et al., 2016).

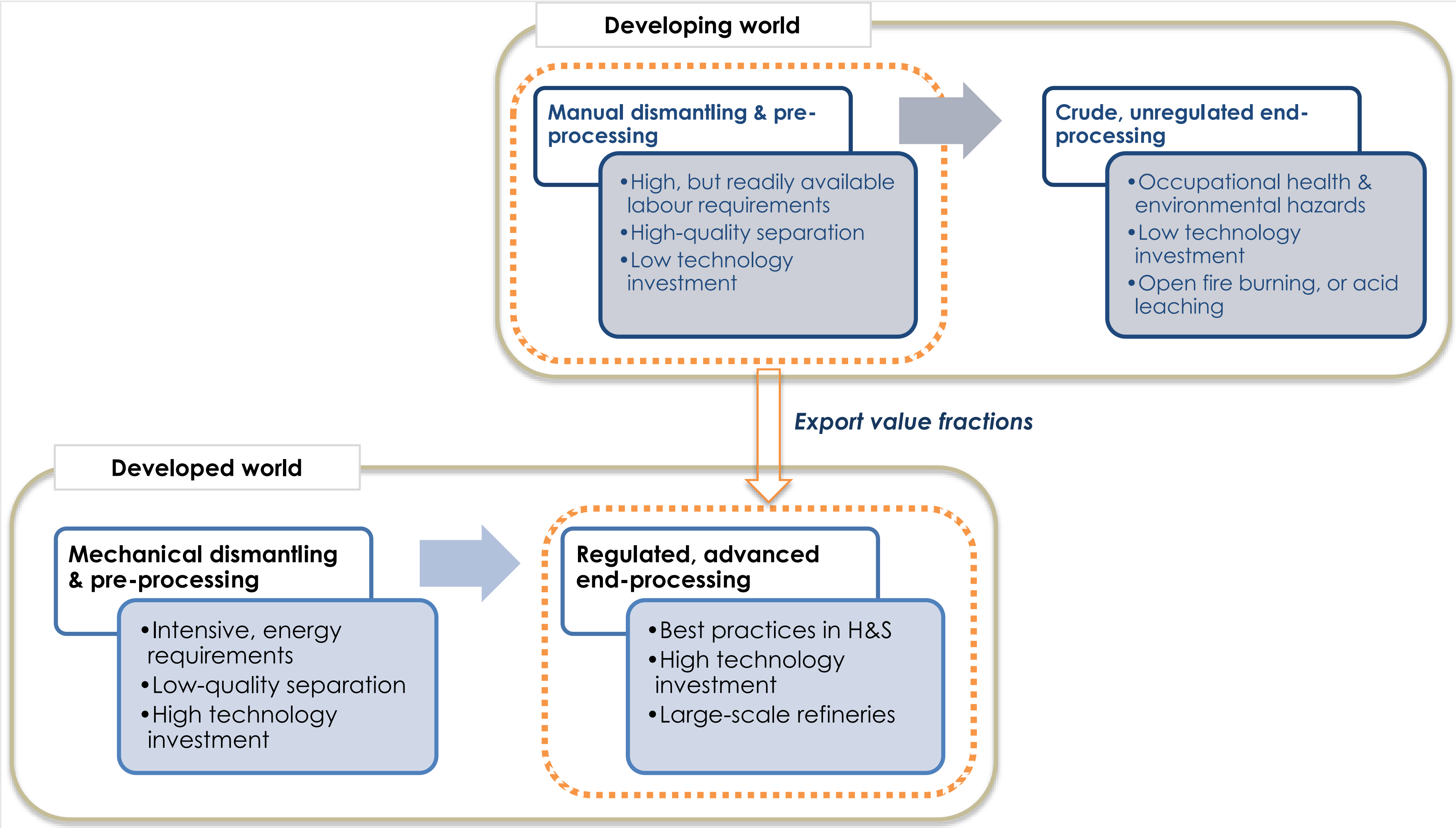

Figure 9: Best of 2 Worlds Philosophy

The Bo2W philosophy is considered a win-win scenario in that it provides job opportunities in the developing world while preventing potential environmental and health risks. However, it puts forward a commodity chain in which the developing world is exploited for its low-cost labour.

Additionally, valuable resources are exported to the developed world, while the low-value fractions residues are left behind (Bocken et al., 2016). Therefore the environmental problems associated with the disposal of low-value fractions or residues will remain the problem of developing countries. This is comparable to the consequences of mineral extraction in extractive economies as discussed in Section 2.2.3. Post mining and processing of mineral ores, the gangue mineral phase remains behind in large tailings dams generating acid run-off and other environmental impacts.

Furthermore, the Bo2W philosophy is not exhaustive of the many alternative scenarios and technologies available. Emerging economies such as SA have medium technology investment in separation processes beyond manual dismantling. In addition, there is a growing interest in developing a local end-processing sector.

2.5 Chapter Summary

The CE provides a conceptual framework in which to discuss and plan for secondary resource economy development. However, more work needs to be done in terms of its implementation in various contexts. The biggest obstacle is shifting the definition of waste as an environmental and financial liability to a resource or value stream. However, this comes with various limitations including legislation, existing waste management systems, as well as the technical and pragmatic considerations which include the cost of and technologies available for recycling and value extraction, as well as dealing with negative value residues.

It could be argued that the Bo2W philosophy is currently adopted in SA to a certain extent, however, there is interest in the development of a local end-processing and manufacturing sector. Furthermore, there is scope for adapting existing technologies to the SA context as well as overcoming any associated challenges. It is also important that the divide between the developed and developing world is not perpetuated as the Bo2W philosophy threatens to do.

For the e-waste management industry in SA, it is essential to consider economies of scale when choosing a suitable processing technology. Furthermore, strategies for more ‘urban mines’, or collection infrastructure, is required for the long-term sustainability of the industry.

A deeper understanding of the South African context is necessary to find the most suitable technology for e-waste end-processing. An investigation into the legislative environment, quantities and flows of e-waste as well as the existing waste management system should be considered.

3 Research Approach

As mentioned in Chapter 1, this research study builds upon the knowledge that there is a limited understanding of the feasibility of existing e-waste end-processing technologies for implementation in the South African socio-economic and legislative context. Therefore, this research intends to find out what are the key barriers and enablers to implementing e-waste end-processing technologies in SA.

This research initially focused on developing a process for metal extraction from waste PCBs. It was proposed to investigate the techno-economic feasibility of this process in the SA context, where recyclers are known to deal with relatively small volumes of e-waste. However, upon reviewing literature it became clearer that technologies are well developed, while the true problem is that there is a myriad of barriers to implement technologies, thus necessitating the study that follows.

This chapter introduces the research questions that emerged from the literature review. The research approach is then presented and justified in terms of the methods used for data collection, analysis and verification, as well as the ethical considerations. Finally, the chapter concludes with the research significance.

3.1 Research Questions

The overall aim of the research is to develop a deeper understanding of the industry's development potential in terms of the available technology options, as well as the socio-economic and legal factors affecting the local implementation of technologies. Furthermore, the research study aims to make recommendations for researchers, industry, and government bodies to move towards a secondary resource economy for e-waste in SA.

The following questions were set as guidelines to fulfil this aim and corresponding objectives as outlined in the Introduction.

Objective 1: *Develop a deeper understanding of the development and organisation of the e-waste industry in SA.*

1. How has the e-waste industry historically developed in SA?
2. How is the current e-waste industry organised and governed?

Objective 2: *Investigate existing technology options for e-waste end-processing.*

3. What are the existing technology options for e-waste end-processing?

Objective 3: *Identify the socio-economic and legal legislative barriers and enablers for local, small-scale end-processing for value extraction from e-waste.*

4. What contextual factors affect the implementation of e-waste end-processing technologies in SA?

Objective 4: *Provide recommendations for the next steps in establishing local e-waste end-processing further research and development, addressed to research institutions, industry and relevant government bodies.*

5. How can research institutions, industry and relevant government bodies address these factors?

3.2 Methodology

The qualitative research methods used aim to uncover current and representative narratives from key stakeholders within the e-waste recycling industry in SA. These methods included an extensive literature review, interviews and informal discussions with key stakeholders, as well as site visits to local recycling plants. This research followed the outline proposed by Creswell (2014) as is illustrated in Figure 10.

The raw data collected included interview audio recordings, field notes and photographs. Additionally, an extensive review of academic articles, company reports, media reports and publications, and policy documentation was completed. This data was then organised and prepared for analysis through transcription, cataloguing and summaries. After reading and summarising the data, coding would be done manually using thematic analysis. Data was also verified at different stages of analysis.

These methods will be further described in the following sections including contextual factors, data collection, verification and analysis.

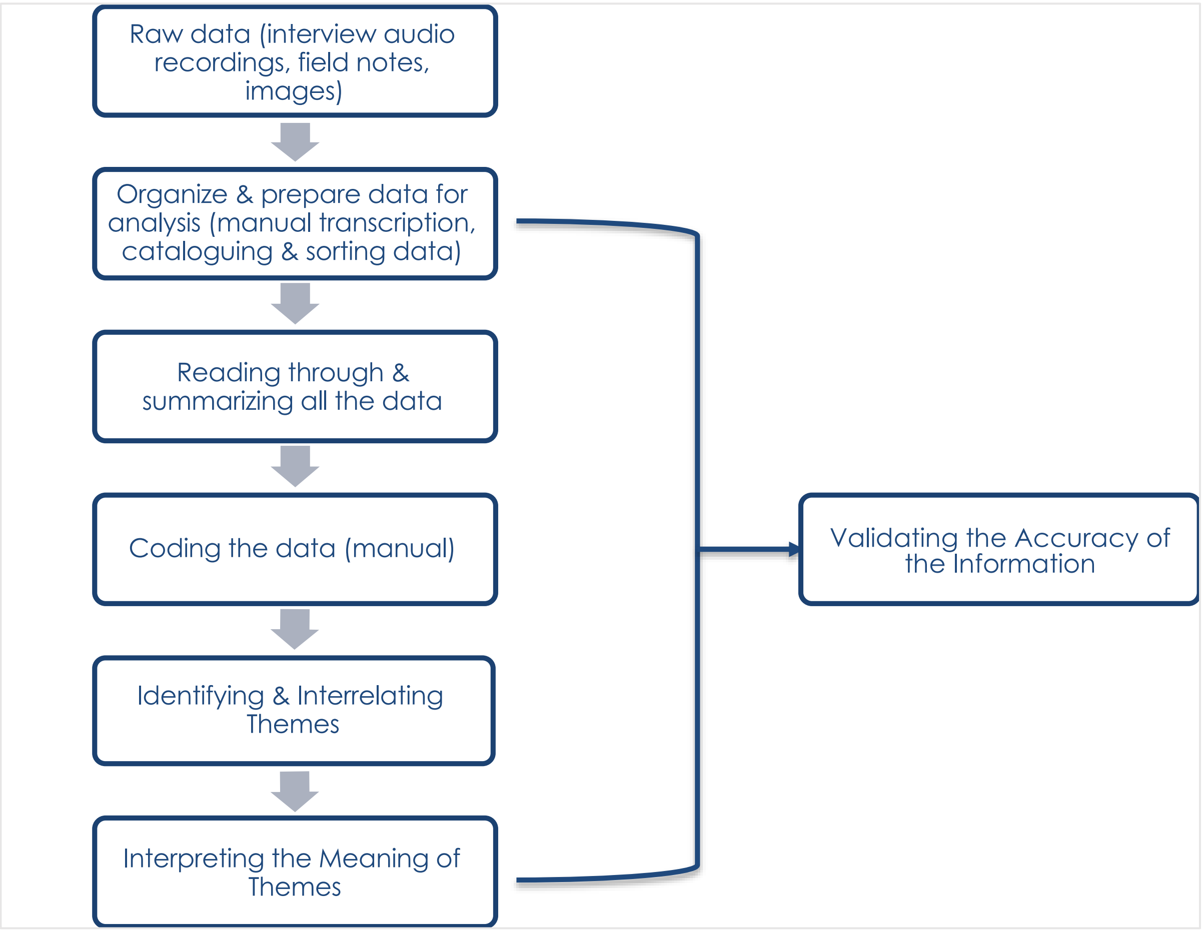

Figure 10: Summary of data analysis and verification procedure (adapted from Creswell, 2014)

3.2.1 Data Collection

Data has been collected from the following sources:

i) An extensive literature review of academic articles, company reports, media reports and publications, and policy documentation;
ii) observations and photographs at site visits of e-waste processing operations;
iii) formal interviews with key stakeholders; and
iv) informal conversations with stakeholders.

The literature review provided insight into the global and South African context, which included e-waste legislation, value chain activities and stakeholder information. Most of the studies on the status quo of the industry are over 10 years old (Finlay, 2005; Widmer & Lombard, 2005; Finlay & Liechti, 2008; Dittke, 2009; Newson & Dittke, 2009).

However, the industry has undergone significant developments since then, which is highlighted in the latest report by Mintek in partnership with the Council for Scientific and Industrial Research (CSIR), published in March 2017. This particular report provided a comprehensive study on the e-waste technology landscape and is used as the foundation upon which this research has been built.

The literature review was complemented with primary data collected through interviews and site visits. The initial interaction with the e-waste industry was via Ms Susanne Karcher, an environmental consultant and the director of the Southern African E-waste Alliance (SAEWA, an e-waste industry network and voluntary industrial association). She was contracted to organise and facilitate site visits to e-waste recyclers in the Western Cape (April 2017) and Gauteng (February 2017) regions. These site visits were to organisations that primarily formed part of the SAEWA membership and affiliates network, and are otherwise supportive of the SAEWA's mission, vision and objectives. However, two site visits namely, Smiley's Electronics and TraX Interconnect, were contacted via other networks. The sites were chosen based on the company profile, size of the operation, e-waste activities, location as well as availability and willingness to participate in the research. Additionally, a visit to an Indian e-waste recycler occurred as part of the researcher's personal trip to Bangalore, India in July 2016. The organisations that were visited are listed and described in Table 9.

Table 9: List and description of organisations visited as part of fieldwork

	Organization	Site information	Location
Western Cape			
1.	NC Electronix Pty Ltd	Small-scale, family business; transitioned from refurbishment and electronic repairs to e-waste collection and dismantling.	Paarl
2.	Square Mobile	E-waste collection facilitator for electronic repair stores in community shopping centres; conducts e-waste awareness campaigns, rewards for recycling programs, and community-based mobilisation for e-waste recycling.	Mitchell's Plain
3.	Cape E-waste	Medium-scale collection and dismantling facility; owners used to work for Desco; now a collection agent for Desco.	Brackenfell, Cape Town
4.	Smiley's Electronics	Informal e-waste collector who does electronic repairs at home and sells repaired goods as an informal hawker; subsistence-based business.	Pinelands / Maitland Eco-Village, Cape Town
5.	SA Metals Group	Oldest, large-scale scrap metals recycler in SA, with multiple branches all over the country; family-based business.	Epping 2, Cape Town
6.	TraX Interconnect (Pty) Ltd	Manufacturer of PCBs; buys metal-based products and sells metal scrap to scrap dealers.	Diep River, Cape Town
	Organization	**Site information**	**Location**

Gauteng			
7.	Reclite	One of two lighting recycling company, in SA, with growing capacity.	Germiston
8.	Mintek	Government-funded research institution, conducted pyrometallurgical testing on metal extraction from PCBs, plastics pelletising plant, and published the e-waste recycling technology landscape report in 2017.	Randburg
9.	Sindawonye	Large-scale e-waste recycling company, mainly deals with large tenders from telecommunication companies; has a sister company that recycles e-waste plastics into wood-plastic composite furniture products.	Johannesburg
10.	Desco Electronic Recyclers cc	One of the largest e-waste recyclers in SA, fully legally compliant, family-owned business, involved in the collection, dismantling, pre-treatment, and exporting of PCBs and plastics.	Kempton Park
International			
11.	E-Parisaraa Pvt. Ltd.	E-waste recycler conducting research into technology for value extraction via government funding; manufactures precious metals-based ornaments; involved in Li-ion battery recycling; employs local community members.	Bangalore, India

The site visits provided further insight into the process technology, the traceability procedures, and the health and safety practices used by industry operators. It also allowed for observations to be made based on reality instead of expectation. Furthermore, it provided insights into the social and environmental context of the employees and infrastructure. Site visit observations and informal discussions were recorded using field notes. Some photographs were also taken when allowed and will be used to further illustrate information gathered.

The type of data recorded based on observations and informal discussions during the site visits include:

i) technology and operations,
ii) material flows of feedstock and products,
iii) agenda and motivations of recycler,
iv) perspectives on waste legislation, and
v) any other interesting or surprising pieces of information.

Field notes were summarised and emailed to the organisations for information verification. This verification step provided research participants with the opportunity to correct, add or remove any information. The information used from field notes in the text will be referenced as follows (organisation, site visit, year of visit), for example, (NC Electronix, site visit, 2017).

Formal interviews were organised with three of the organisations visited in the Western Cape, namely, Cape E-waste, NC Electronix and Square Mobile. These organisations provided a rich perspective on small-to-medium scale recycling of e-waste in the Western Cape in terms of trade, operations and navigating legislation. Ms Karcher was also interviewed as a key stakeholder in the industry and provided a high-level analysis given her 10 year-plus experience in the waste management field, background as an environmental consultant and wide network of recyclers in the local and international industry. Furthermore, interviews with an informal subsistence refurbisher and an environmental lawyer in the Western Cape were conducted to gain deeper insights into the informal sector and legislative environment, respectively. A list of the interviewees, description of their role, organisation, location and expertise are presented in Table 10.

Table 10: List of interviewees and description of their role, organisation, location and expertise

	Interviewee Descriptor	**Description of role and organisation**	**Description of information gathered**
1.	Susanne Karcher	Environmental Consultant & Chair and Coordinator of the Southern African E-waste Alliance (SAEWA)	High-level overview of the e-waste recycling sector; environmental legal compliance; product market and trade information
2.	Environmental Risk Officer, higher education institution	Environmental Risk Officer at a higher education institution	Organizational perspective on e-waste management; waste information registration and requirements
3.	NC Electronix	Owner, NC Electronix - Small-scale e-waste business operating outside of Cape Town Central Business District (CBD)	Insights into small-scale e-waste recycling operations, flows, product markets, value chain and stakeholder interactions
4.	Square Mobile	Owner, Square Mobile – small-scale start-up focusing on mobile phone collection & recycling.	Insights into e-waste collection logistics; e-waste awareness campaigning and community-based mobilization; perspectives on the legislative procedure for a start-up e-waste recycler
5.	Cape E-waste	Owners, Cape E-waste - medium-scale e-waste recycler and collection agent to Desco	Perspective on barriers in obtaining full legal compliance, comparison of regional differences in the e-waste business
6.	Smiley's Electronics	Owner of Smiley's Electronics, an informal refurbisher and reseller	Informal sector perspective
7.	Mark Dittke	Managing Attorney, Dittke Attorneys – specializing in Health, Safety and Environment	Insights into policy and legislative framework in SA, auditing services

Interviews followed a semi-structured approach to create a sense of conversation and to provide scope for the revelation of personal lived experiences while still obtaining information relevant to the research objectives.

The interviews comprised of a mixture of the following types of questions:

i) *General*: who, what, where, why, and how
ii) *Explanatory*: experiences, narratives, personal stories
iii) *Visionary:* if you could change anything, what would it be and why? How would you do things differently? What would be your ideal…?

Questions around particular thematic areas were posed based on the information gathered through the literature review and initial site visits. Some of the thematic areas used were technology; materials flows; policy and legislation; value chain activities; and stakeholder networks. Sample interview questions can be found in Appendix A.

The interviews were audio-recorded upon consent of the interviewees, using a battery-operated Olympus audio recorder. The length of interviews ranged between 45 – 150 minutes depending on the availability of the interviewee. Interview recordings were transcribed using Microsoft Word. The interview transcripts were then summarised and sent to interviewees for information verification as well as the opportunity to add, correct or remove any information. Any follow-up questions that arose were posed via email or telephone communication depending on the preference of the interviewee. These were documented and also used for data analysis. Any information used from interview transcripts in the text will be referenced as follows (interviewee descriptor, interview, year of interview), for example, (Karcher, interview, 2017).

Informal discussions were also conducted and documented by the researcher, but not audio recorded. A list of these discussions and a brief description of the information gathered can be found in Table 11. A summarised report of these informal discussions was also sent to each participant for verification and feedback. These will be referenced in-text as follows, (Description of informant, informal discussion, year of discussion), for example, (Environmental Officer - provincial government, informal discussion, 2017).

Table 11: List of informal discussions

	Description of informant	Description of information gathered
1.	Environmental Officer within provincial government	Insights into developments within provincial government and municipalities regarding e-waste
2.	Representative from a green economy network and research agency	Stakeholder analysis of e-waste industry in SA; market intelligence reporting for the waste sector in the Western Cape.
3.	Minerals industry independent consultant	Suspicions regarding illegal export of precious metals disguised as e-waste
4.	Sales representative of large, international precious metals smelter and refinery	International perspective on e-waste processing, importing and feedstock supply
5	Jeweller in SA	Produces jewellery from reclaimed metals from e-waste received from Gauteng Refinery

3.2.2 Data Analysis

The collected data was analysed using Thematic Analysis in which repeated patterns or themes are searched across a data set and used to draw up conclusions as well as key ideas to be discussed. Furthermore, it seeks to provide a comprehensive overview of any contextual phenomena, experiences or themes presented in the data. This method is usually used in conjunction with other more intricate analytical methods such as grounded theory, discourse analysis or interpretative phenomenological analysis. However, thematic analysis is argued to be more flexible to use in isolation than using any of the aforementioned methods (Braun & Clarke, 2006).

These themes can be identified through inductive or deductive approaches. The inductive approach involves themes emerging from the data itself with no pre-existing theories or framework. The deductive approach involves finding themes in the data directly related to existing theory or ideas (Braun & Clarke, 2006; Schulz, 2012). A mixed inductive and deductive analysis was conducted for this study. This was achieved via coding of the interview transcripts, site visit reports and informal discussions. Codes are any relevant or interesting ideas, phrases, or concepts identified in the raw data that represent feelings, opinions, facts, or narratives detailed in the dataset. Codes can then be categorised and collated into themes or thematic areas (Braun & Clarke, 2006).

The initial themes were obtained prior to coding and formed the deductive component of the coding process. These were themes and ideas that the researcher had identified and considered salient from literature. These themes were used during the development of interview questions and guidelines and provided initial categories for the coding process. Additional codes were obtained from the interview experience itself, site visits, informal discussions and through the process of listening to audio recordings of interviews and the transcription thereof. Further codes were obtained during the process of summarising interviews as well as through the study of interview transcripts multiple times. This type of coding forms part of the inductive approach, whereby themes emerge from the data itself (Schulz, 2012).

As previously mentioned, each interview was transcribed and summarised or paraphrased. Thereafter the summarised data was organised under the initial themes. These summaries provided an initial overview of the data and formed the first stage in the data analysis. Each interview transcript, site visit report and informal discussion report was then coded in separate Microsoft Word documents. This formed the second stage of the data analysis.

Coded data included quotes, phrases or paraphrased ideas and interpretations. Codes were then grouped into sub-themes and finally overarching themes that have emerged during the coding process, thereby developing a thematic map. This is where the interpretative aspect of this data analysis method.

An example of a thematic map is shown in Figure 10. In this example, the overarching theme is 'Securing volumes', an example of a sub-theme is 'Education and Awareness', and the codes within that sub-theme are 'Shared Responsibility' and 'Managing Expectations'. These are the themes and ideas that will be analysed, reported and discussed in the results sections.

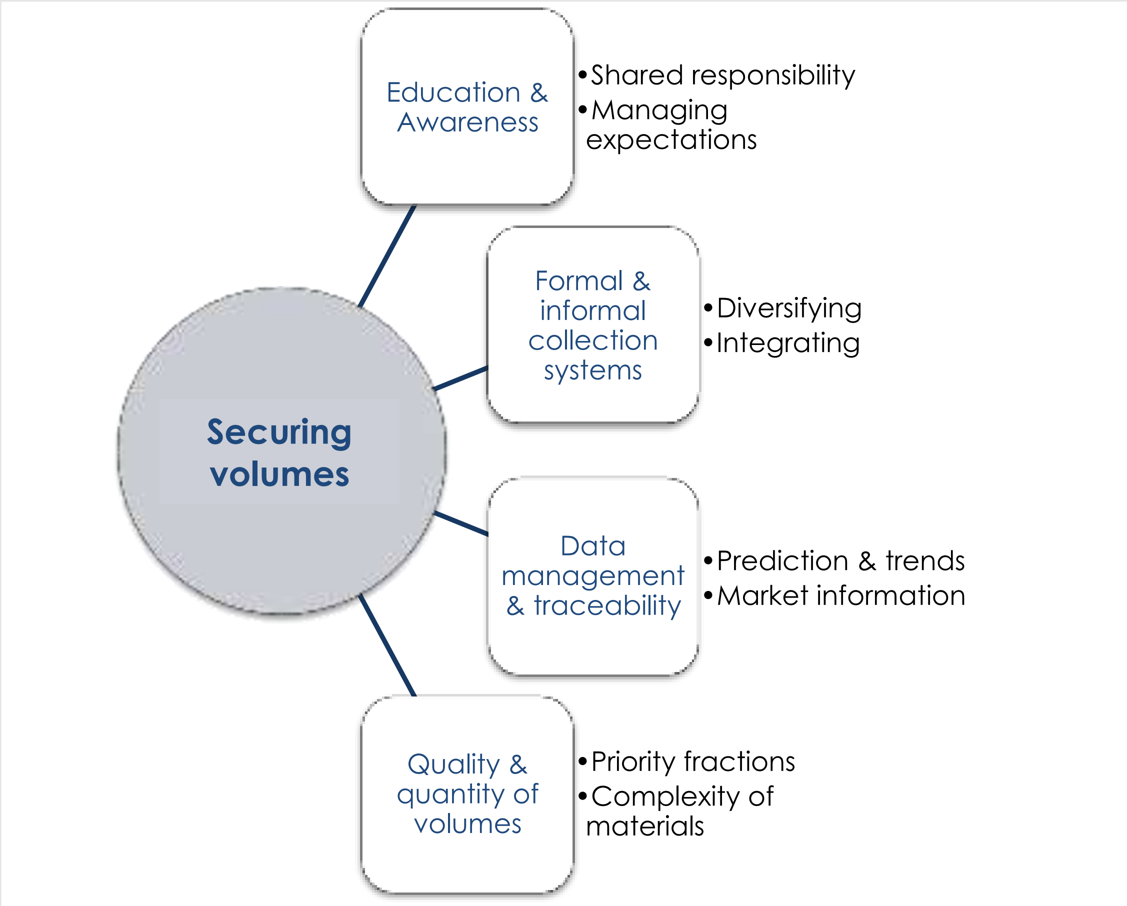

Figure 11: Example of thematic map developed during the coding process

The final overarching themes are presented in Figure 12. The overarching themes all form part of factors that contribute towards industry development, which is the main focus of the research questions.

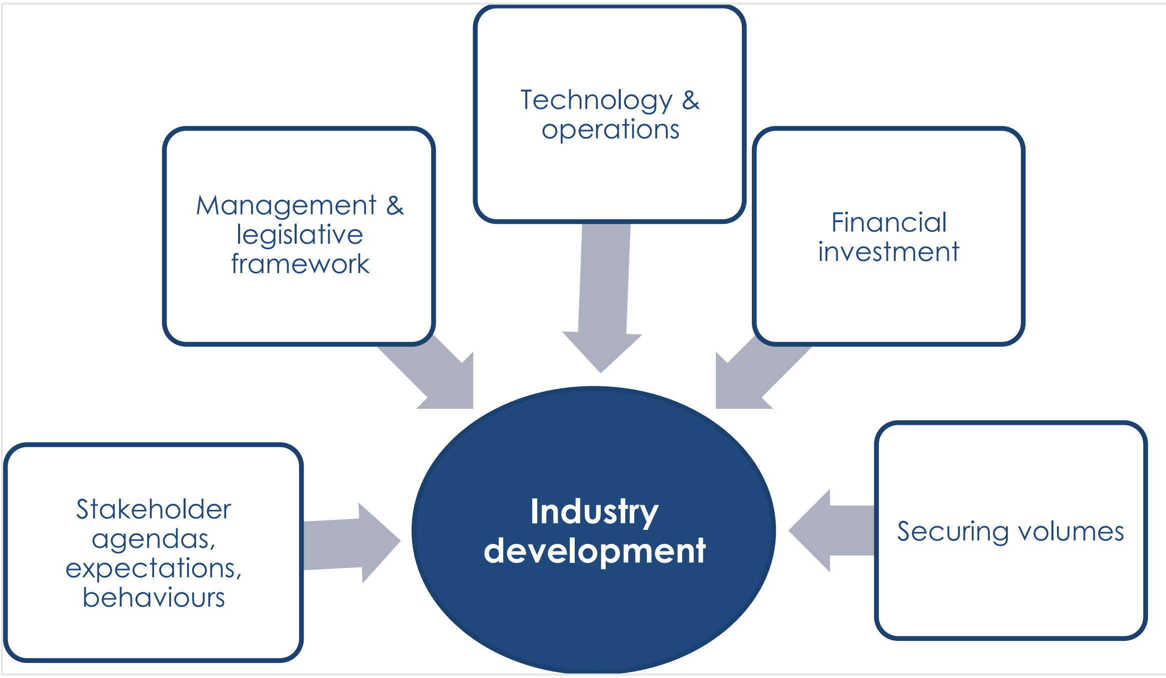

Figure 12: Refined thematic areas developed during the coding process

3.2.3 Data Verification & Validation

Data was validated in three ways, namely, member checking, triangulation, and peer debriefing as described by Creswell (2014). Firstly, validation was sought through seeking feedback from research participants. This was done by sending them summarised reports of the interview transcripts, site visit reports and informal discussion reports. They were invited to add, remove or correct any of the information listed, as well as identify any confidential or sensitive matters that should not be included in the research study.

The second was via triangulation of data from different sources. Corroborating or conflicting ideas from different interviews, observations and literature were highlighted and flagged for further discussion, coding and development of themes.

Lastly, continuous peer debriefing and collaborative coding were performed with fellow researchers, namely:

- Dr Thandazile Moyo, a postdoctoral fellow in the MtM Research Initiative, Department of Chemical Engineering, UCT

- Andreas Stien and Helen Due, MtM interns in association with the Social Enterprise Academy and UCT Graduate School of Business

Peer debriefing and collaboration was done by writing codes on post-it notes for each interview, grouping codes into sub-themes and overarching themes. This exercise and the discussion that arose from it brought about new ideas and richness to the data analysis.

The interview unpacking and grouping techniques used were based on Design Thinking Methodology (Hasso Plattner Institute of Design at Standford, 2011). The template used to unpack interview data in a peer debrief session is shown in Table 12. The interview data was unpacked by filling in the template, highlighting the interviewee and their context (We met…), what information was received (They said…), and the interpretation of the information (Insights). Additional information was also highlighted such as surprising or interesting pieces of information and observations noted during the interview such as body language, surroundings, or any other phenomena.

Table 12: Matrix used to unpack interview data during peer debriefing

We met… (user + context)	They said…	Insights	This was interesting/ surprising…	Observations

Theme grouping was performed similarly to thematic analysis, however performing this in a pair or group of three revealed additional insights and perspectives on the collected data. All formal interviews were done using peer debrief sessions after transcription and summaries were complete.

Photographs of the abovementioned processes can be found in Appendix B.

3.3 Research Context and Limitations

A limited number of stakeholders participated in this research due to time and accessibility constraints. Furthermore, this research took place during a dynamic and transient point in the legislative and political context of the South African e-waste industry. This called for regular check-ins with recent news articles and follow-ups with interviewees. This makes particular reference to the call for industry waste management plans and the recent ban of plastic waste imports to China during the course of the study. This may reveal that some data is outdated by the time of publication of this study.

The industry and trade environment exhibited high competition and dynamism, which was spurred on by the high demand yet limited access to e-waste. Some recyclers held back on information such as pricing structures, while others tried to obtain information from the researcher. This may have affected the type and quality of data received from interviewees due to the sensitivity of the information.

Furthermore, the diversity and turnover of recyclers in the industry ranging from formal, semi-formal and informal, as well as small, medium to large scale, presented a challenge in getting a comprehensive overview of perspectives and information. Additionally, some recyclers were more difficult to contact than others due to the nature of their operations, for example, informal processors with no formal location or contact details for their operations. Nevertheless, a rich collection of data was obtained due to the complexity of the industry and diversity of research participants.

The qualitative research methods used are interpretative by nature, thus observations, interviews and discussions may be interpreted differently by another researcher. This is influenced by the individual lenses of positionality, expertise, experience and agenda through which the data is interpreted. Furthermore, the data itself presents many instances of hearsay which may only be opinion or rumours reported by research participants. The researcher was careful to avoid using such data and made a point to verify, corroborate and gain clarity on data used in this study.

3.4 Research Ethics

This research obtained ethical clearance from the research ethics committee of the Faculty of Engineering and the Built Environment. A copy of the clearance certificate can be found in Appendix C.

Free, informed consent from research participants was sought for the following:

- participation in the research for the outlined purposes described beforehand;

- use of information shared in the interview as well as the data handling procedures;
- audio recording of the interview;
- preference of anonymity - use of participants' personal details, and/or organisations' details.

Some research participants opted to present the organisation they work and not have their names mentioned. While others, namely Susanne Karcher and Mark Dittke were happy to represent themselves and their organisations.

Participation in this research project was on a voluntary basis and interviewees were invited to withdraw their participation at any point in the research process if they so wished. The research outline was explained and made available to potential participants before participation in the research. This research also provided opportunity for the participants and/or their organisation to remain anonymous. Some participants gave permission to disclose their names, while others wanted their names to remain anonymous, but did not mind having their company name disclosed.

The data collected in the form of interview transcriptions and site reports were shared with and approved by research participants before submission of this dissertation. Raw data in the form of field notes, interview transcripts and summaries have been filed and stored with the researcher and will only be shared with a third party upon consent from research participants.

4 Overview of South Africa's Waste Management System: History & Governance

The waste management sector in SA is largely shaped by its legislative environment. SA has a unique history in terms of the development of waste policies and legislation. This is characterised by its recent move away from landfilling as its primary waste management strategy, towards contributing to a secondary resource economy through recycling and extended producer responsibility (EPR).

The chapter will begin with a comprehensive historical background of waste management legislation in SA, followed by an overview of developments in the e-waste industry. These insights will provide the understanding necessary to further examine opportunities in the e-waste industry.

4.1 Waste Legislation & Governance in South Africa

SA has a three-tier governing system – national, provincial and municipal (Finlay & Liechti, 2008). Waste management policies and legislation are set by national government, with not much specific waste legislation set out at the provincial level in SA. However, there are relevant municipal-specific waste legislation in the form of by-laws (Dittke, interview, 2018). This section will mainly deal with national waste policies and legislation which is managed by the national Department of Environmental Affairs (DEA).

The mapping of waste legislation in SA, by Godfrey & Oelofse (2017), resulted in the identification of four key stages in the development of the waste economy as illustrated in Figure 13. These four stages are namely, i) the age of landfill, ii) the emergence of recycling, iii) the flood of regulation and iv) the drive of EPR. There are particular pieces of legislation characteristic to the development of each stage. These will be discussed in more detail in the sections to follow.

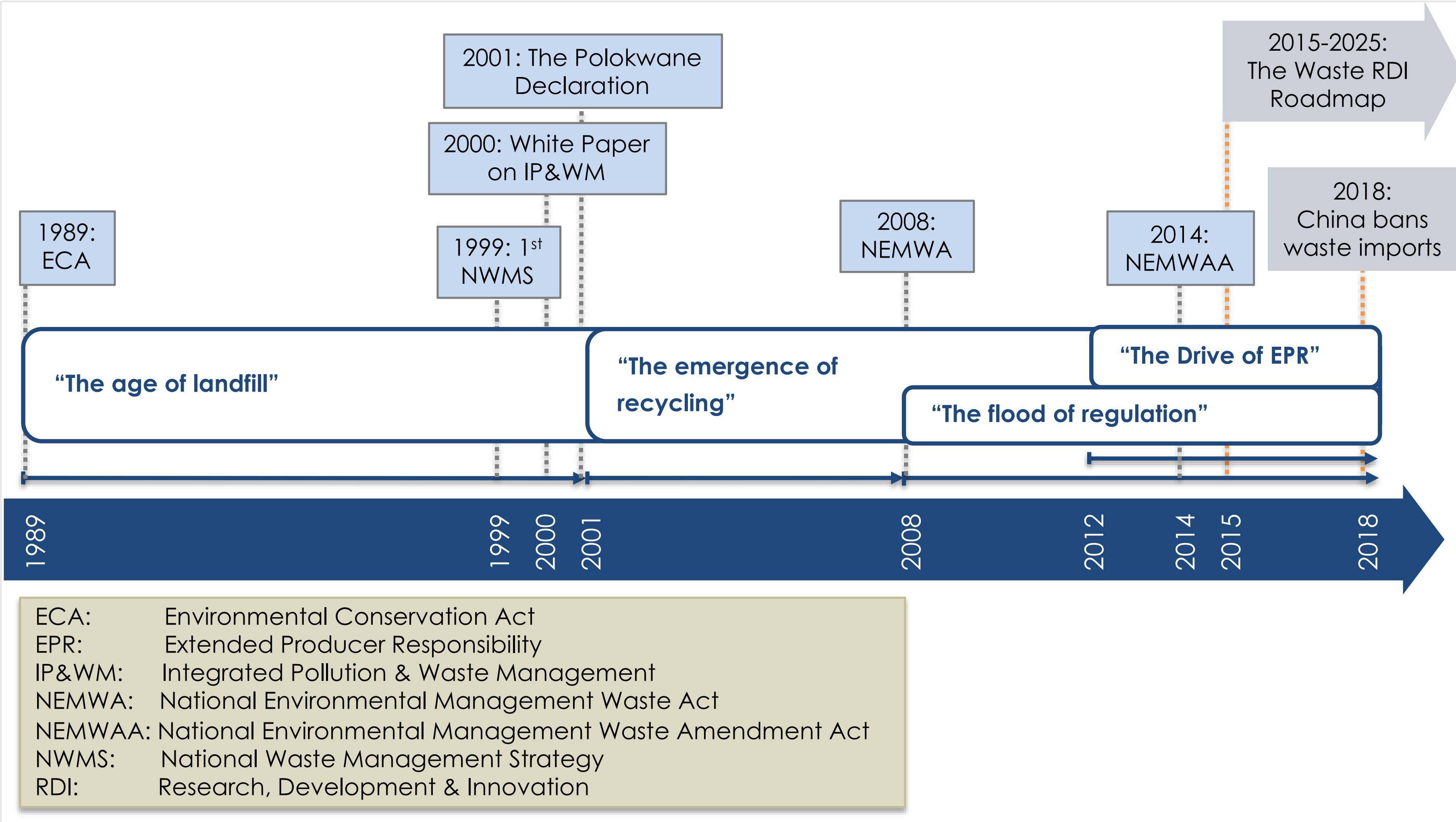

Figure 13: Developments in the South African Waste Management Industry (adapted from Godfrey & Oelofse, 2017)

4.1.1 The Age of Landfill

The age of landfill is the first stage in the development of SA's waste economy. Godfrey & Oelofse (2017) rightfully point out, that SA is yet to emerge from the age of landfill. In 2011, 90% of the waste generated in SA was disposed of in landfill (DEA, 2012). This is driven by the relatively low landfill gate fees compared to European benchmarks. Furthermore, certain waste streams, such as garden waste and clean builders' rubble, are free to dispose of in landfills to combat illegal dumping. In addition to the low costs of landfill disposal, the lack of alternative, economical waste management solutions, and the seemingly extensive land availability also add to the perpetuation of "the age of landfill" (Godfrey, 2016; Godfrey & Oelofse, 2017).

Landfilling is the earliest and most dominant waste management solution in SA, for both general and hazardous waste (DEA, 2012; Godfrey & Oelofse, 2017). This is true for most developing countries, due to their basic technology and financial investment. However, there are health and environmental concerns accompanying landfilling, which include soil and groundwater pollution due to uncontained leachate, and air pollution from gases produced from organic material (Mmereki et al., 2016). These concerns have spurred on the development of policies and regulations to ensure proper landfill design and maintenance, marking environmental stewardship as the earliest agendas in waste management legislation.

Landfill policy development was initiated by the Environmental Conservation Act (Act 73 of 1989, as amended) (ECA) together with a minimum requirements document series, and thereafter norms and standards to provide technical guidance for landfill disposal (Godfrey & Oelofse, 2017). These policy documents were financially and technically supported by the Danish Cooperation for Environment and Development (DANCED). This essentially put SA's landfill legislation on par with international waste management standards.

SA has both general and hazardous waste landfills. These are designed to contain these types of wastes without posing a threat to the environment. The disposal costs for hazardous landfill sites are expensive due to the greater environmental risk insurance, higher costs for additional disposal methods used such as cement encapsulation and underground burial, as well as closure funds.

Although SA's legislation for landfill disposal is comparable to international standards, the implementation thereof only began in recent years. In 2009, 431 out of the 826 landfill sites in SA (52.1%) were unlicensed because they existed before any environmental legislation was passed. In 2016, a few years after the licensing project was implemented by the DEA, only 14 (1.6%) landfills were unlicensed, 55 (6.7%) in the process of being licensed, and 90 (10.9%) privately owned and decommissioned. The rest have either been licensed or were dumpsites that have been cleaned up (DEA, 2016a).

Although there are now fewer unlicensed landfills, there is still a risk of poor landfill design and maintenance of licensed landfills, resulting in adverse environmental and health impacts. This is especially true for hazardous waste streams such as e-waste fractions.

Godfrey (2016) highlights that most of SA's municipal waste landfills are poorly designed and operated, which introduces a potential environmental threat to air, soil and groundwater systems in the surrounding areas. However, there are mixed views as to whether unprocessed e-waste poses an environmental or health risk (Finlay, 2005).

Studies have proven that metal leaching from e-waste into landfill leachate in simulated test environments does occur, however, the significance in terms of concentrations over time is uncertain. This is dependent on rainfall, volumes and types of e-waste, as well as the extent to which e-waste has been weathered (Spalvins et al., 2008; Kiddee et al., 2013). Furthermore, most modern landfills are lined to prevent seepage into soil and water systems, however, seepage would be a concern for older or poorly designed facilities without proper lining. It is recommended that further research should be conducted into the leaching of metals in existing municipal landfills in SA over time.

Specialised landfill sites for hazardous fractions do exist in SA but still does not provide a long-term, sustainable solution. Recycling, as an alternative and more sustainable solution to waste disposal in landfills, presents the next phase for the South African waste sector.

4.1.2 The Emergence of Recycling

Recycling, as an alternative to landfill in SA, was first formally presented in the first National Waste Management Strategy document (NWMS) in 1999, and the White Paper on Integrated Pollution and Waste Management (IP&WM) in 2000. However, commitment towards recycling was only made by the government in the Polokwane declaration which was published in 2001. This marked the beginnings of the second stage of waste management legislation in SA, “the emergence of recycling”. The declaration set the following targets for government, business and civil society: a 50% reduction of waste generated, a 25% reduction in landfill volumes, and a zero-waste plan by 2022. Although there was no legislation enforcing these targets at the time, there has been growth in the recycling industry primarily through the efforts of the private sector (Godfrey & Oelofse, 2017).

Private sector initiatives include voluntary material organisations such as scrap metal dealerships, paper and packaging recycling initiatives, including Collect-A-Can, Paper Recycling Association of SA (PRASA) and the Polyethylene Terephthalate Plastic (PET) Recycling Company (PETCO), as well as other recyclable buy-back centres. These initiatives are examples of voluntary EPR schemes in SA. These initiatives have had a significant impact on the implementation of recycling technologies as well as the establishment of the waste economy in SA.

However, there are some inhibitors to these initiatives, which include the poor collection infrastructure as well as the lack of end-user markets for recycling products (Godfrey & Oelofse, 2017). Developing the collection infrastructure will ensure increased collection rates and thus reliable volumes of recyclables to achieve the necessary economies of scale for recycling technologies. In addition, securing end-user markets, which would ideally be the local manufacturing industry, would create the necessary demand for recyclable products to further develop the industry.

Municipalities were urged to implement the first NMWS and support private sector initiatives in the shift towards recycling and separation at source. This was encouraged through the aid of guidelines on the implementation of waste collection systems and recycling activities. These guidelines were developed through the support of the Danish International Development Agency (DANIDA). However, due to the limited engagement of civil society and insufficient efforts from municipalities, there is still a very limited integral culture of recycling in SA. This is apparent by the lack of separation-at-source initiatives and collection of recyclables. Additionally, there is a lack of integration of recycling schemes into the municipal waste collection system. The majority of municipal contractors remain an under-utilised resource for the collection and sorting of recyclables. Reasons for this include insufficient funding and resources to implement.

However, this gap was slowly bridged through the informal waste picker community who makes a great impact on collection rates of recyclables, thereby linking the service- and value chains (Godfrey & Oelofse, 2017). Waste pickers collect recyclables from residential and commercial generators, as well from dumpsites and landfills. These intercepted recyclables that would otherwise be disposed of in landfills or illegal dumpsites, are sold to buy-back centres or directly to recyclers in the value chain. This linking of economic chains is illustrated in Figure 14.

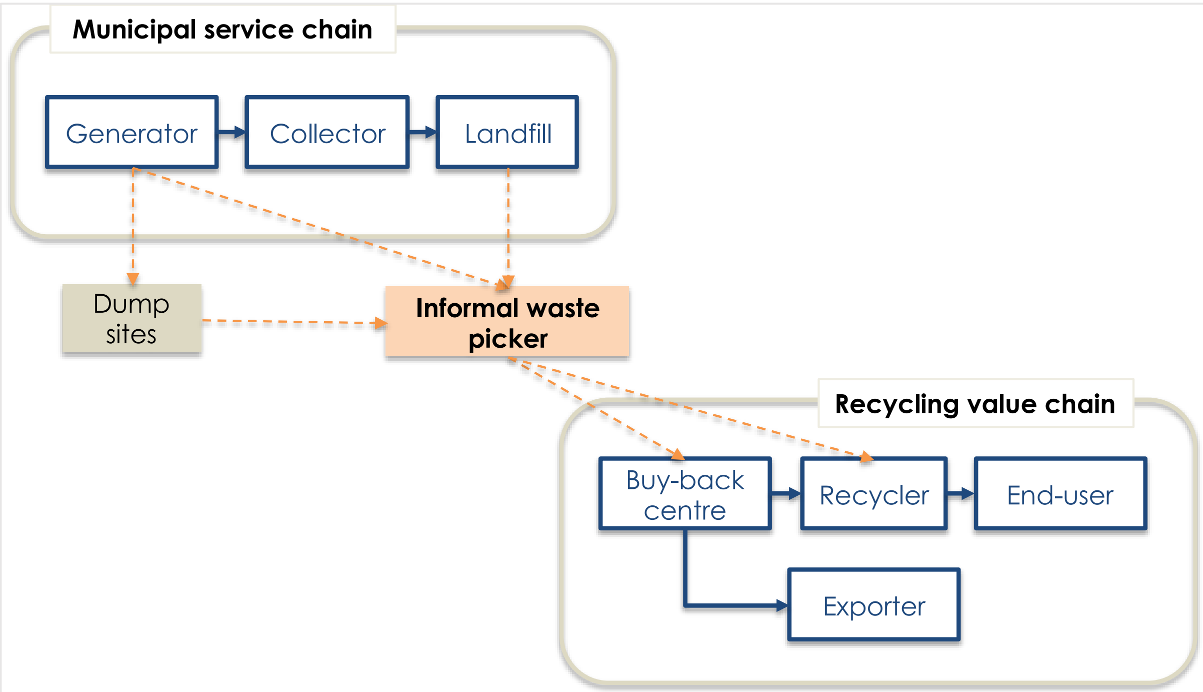

Figure 14: Role of the informal waste pickers in South Africa, linking the municipal service- to the recycling value chain (adapted from Organisation for Economic Co-operation and Development [OECD], 2015)

On the one hand, this informal economic system supports a large and increasing number of unemployed and usually unskilled citizens, as well as adding value to the collection infrastructure and contributing to the recycling value chain. On the other hand, there are growing concerns regarding the negative health and environmental impacts of informal dismantling and recycling activities that may arise (OECD, 2015). These include crude dismantling or destruction of materials to extract the valuable components. One example of this is the burning of copper cables to extract the copper (Bondolfi, 2007). In order to integrate and support the informal waste sector, measures should be put in place to disincentivise these potential hazardous behaviours.

Additional challenges of integrating informal waste pickers into formal systems became evident in the recent mandatory separation-at-source initiative implemented by the City of Johannesburg. The initiative aimed to make separation-at-source mandatory for households that would be provided with a separate collection service for recyclable waste in addition to that for general waste intended for landfill disposal. The recyclable waste collection service was to be carried out by Pikitup, a private waste contractor. The program aimed to be made mandatory for the entire city over the next three years in an effort to divert waste from landfill (Pikitup, 2018a).

However, after just two months of operation, at the end of 2018, Pikitup was forced to suspend their services in certain areas due to violent protest action in the form of burning and stoning of their collection trucks. The protesters were demanding to be insourced by the company even though they had not met the requirements for employment (Pikitup, 2018b). These protesters are believed to be unemployed community members as well as members of the informal waste sector or who were losing access to materials for resale due to this initiative, thereby becoming redundant. This presents a strong indicator that the integration of the informal waste picking community is vital to ensuring the success of formal waste collection and recycling initiatives.

Furthermore, other existing separation-at-source waste management systems at institutions or shopping centres, face the additional challenge of waste contamination. This is primarily due to lack of user engagement and awareness causing the initiatives to fail (SA Metals Group, site visit, 2017, Environmental Risk Officer, interview, 2017). As a result, additional resources such as time and labour needed to conduct proper sorting and cleaning of waste streams become necessary. Therefore, integration and engagement of all stakeholders are necessary for successful separation-at-source and waste collection initiatives.

Due to the lack of end-user markets for recyclable products and the underdeveloped local recycling industry, the exporting of recyclable waste has also become a large part of the SA waste management sector. However, SA experienced, along with the rest of the world, a large disruption in exporting of its recyclable wastes to China.

As of 1 January 2018, China has enforced a ban on the import of 24 waste categories. The categories of waste included several types of post-consumer plastic waste, one grade of unsorted paper, several types of used textiles and metal slags containing vanadium (Bodamer, 2017). A further 32 categories were added to the list – 16 of these, including e-waste, to be enforced by the end of 2018, and the other 16 to be enforced by the end of 2019 (Ministry of Ecology and Environment, 2018). This change in legislation is part of China's campaign towards decreasing pollution and negative environmental impacts, and its upward move on the global supply chain (Reuters Staff, 2018). This ban has made a global impact considering that China was the importer of 45% of the world's waste plastics in 2016.

Although SA is not a significant global source of waste plastics compared to European countries, its plastic recycling industry, largely dependent on exports to China (News24, 2013), has been greatly affected. This extends to the e-waste industry as most of the plastics from e-waste has historically been exported to China (Cape E-waste, 2017, Desco, site visit, 2017). The global plastics recycling industry is now pushed to increase its recycling capacity or find an alternative destination for its volumes. For example, South East Asia is currently a popular choice for the United Kingdom's (UK) waste plastics, as reported by Hook (2018).

Given that the waste sector is primarily run by the private sector alongside the informal waste picker community, as opposed to government initiatives, there has been an increasing amount of changes in waste policy and legislation to control these efforts. This presents the third stage, namely "The Flood of Regulation".

4.1.3 The Flood of Regulation

The year 2008 marked an important milestone for the waste management sector in SA with the promulgation of the first piece of waste legislation, the National Environmental Management: Waste Act 59 of 2008 (NEMWA). The NEMWA applies to different stakeholders such as collectors, producers, recyclers, refurbishers. This legal act is underpinned by sustainable resource management principles offered by the waste hierarchy, promoting reuse, recycling and recovery as opposed to landfill disposal. This act was followed by a 'flood' of related regulations and norms and standards to control and minimise the negative environmental and health impacts of the waste sector. These include regulations on waste management activities, waste information and waste classification, as well as norms and standards regarding waste storage and assessment of waste for landfill disposal, among others.

As the recycling economy was largely driven by the private sector, these new regulations placed a huge burden on businesses to keep up with the ever-changing legislative environment as well as the growing cost of compliance administration in terms of time and money. The legislative environment soon became a hindrance for technology development and innovation of recycling initiatives due to regulatory constraints for implementation thereof. Oelofse and Godfrey (2008) critique that the problem lies in the way waste is defined and consequently approached in SA legislation. They claim that SA legislation defines waste as something the environment needs to be protected from and thus the handling thereof needs to be regulated in all stages of the waste hierarchy, including recycling and recovery.

Therefore, Oelofse and Godfrey (2008) correctly point out the need for SA to redefine waste as a valuable resource. This will not only help implement the upper rankings of the waste hierarchy, but also ensure the development of a recycling, or secondary resource, economy. This view is already held by private sector recycling and voluntary EPR initiatives as previously mentioned. These initiatives have discovered the potential economic opportunities, however, require a legislative environment supports it.

Fortunately, national government has initiated this shift through the emergence of alternative policy instruments to resolve the economic and other systemic issues in the waste management sector. This is further explored in the following section.

4.1.4 The Drive of EPR and other Government initiatives

The national DEA has indicated its aim to drive the waste diversion from landfill agenda, including but not limited to (DEA, 2015b):

(i) banning certain waste streams from landfill,

(ii) encouraging EPR initiatives to fund the waste recycling industries in the form of industry waste management plans (IndWMP), as well as

(iii) supporting Small and Medium Enterprise (SME) development in the alternative waste management technology solutions space.

Therefore, the drivers for waste diversion from landfill are not only from an environmental stewardship perspective but also to promote socio-economic opportunities such as job creation and economic opportunities. Although there is still the view of waste from an environmental liability perspective, the view that waste is a potential resource and economic contributor is beginning to appear.

This agenda is further supported by the Department of Science and Technology (DST) through the implementation of the Waste Research, Development and Innovation (RDI) Roadmap for SA from 2015 - 2025. This roadmap puts emphasis on diverting waste from landfill sites towards value-adding opportunities for sustainable waste and secondary resource management. It is warranted by the R25,2 billion valuation of the waste resources available and potentially lost through landfilling every year in SA. The Roadmap aims to recover R17.4 billion/year through its waste diversion from landfill targets (Department of Science and Technology, 2014).

The DEA is effecting their plans through the sanction of National Environmental Management: Waste Amendment Act, 2014 (Act 26 of 2014) (hereinafter referred to as NEMWAA). The NEMWAA, along with related regulations and strategy plans, is aimed at providing an enabling environment for the waste recycling economy in SA by promoting waste minimisation and alternative waste management practices. At the 22nd biennial WasteCon 2014, the DEA held a reporting session on the NEMWAA to allow delegates the opportunity to familiarise themselves with this new Act. The Deputy Director-General of Chemicals and Waste Management from the DEA, Mark Gordon, highlighted that the three main areas of transformation of waste legislation, were as follows (Institute of Waste Management of Southern Africa, 2014):

- regulatory reforms through NEMWAA, new regulations and the IndWMPs,
- institutional reforms through the Waste Management Bureau (WMB) and,
- economic reforms through the national pricing strategy.

The Minister of the DEA has declared e-waste, lighting, paper and packaging and tyres as priority waste streams. This, therefore, creates the need for IndWMPs for these industries to effectively manage these streams. In order to monitor, implement and build capacity to support the IndWMPs, the DEA has operationalised the WMB as per NEMWAA (Mapulane, 2017). Furthermore, the WMB is also commissioned to manage the collection and distribution of EPR funds.

The first mandatory EPR scheme in the form of an IndWMP was developed and managed by the waste tyre industry through the Recycling and Economic Development Initiative of South Africa (REDISA) in 2013. However, due to concerns regarding poor governance, failure to meet targets, deviations from the plan and misuse of public funds, the waste tyre EPR scheme is under re-evaluation after its five-year tenure. Furthermore, the EPR fee collected from the producer by the Producer Responsibility Organisation (PRO) – which was REDISA in this case – was turned into an EPR tax paid by tyre producers directly to the government. This raised many concerns from the tyre industry that EPR funds would be mismanaged or misdirected by national government (Godfrey & Oelofse, 2017).

The difference between the EPR fee versus the EPR tax is shown in Figure 15. The EPR fee is the industry managed EPR fund scheme whereby PROs collect funds directly from producers or importers to disburse to the waste management industry operators. The WMB would then ensure this process is monitored. The EPR tax is a government-managed EPR fund scheme whereby the South African Revenue Service (SARS) collects funds from producers and importers. The funds then get passed on to National Treasury who passes them on to the WMB to disburse to PROs. Finally, PROs will ensure funds are distributed to the waste management industry operators.

The EPR fee is applied to voluntary EPR schemes such as that for tins via Collect-A-Can or plastics via PETCO, the Polystyrene Packaging Council or Polyco. Whereas the EPR tax is applied for mandatory EPR schemes implemented through IndWMPs as per the National Pricing Strategy for Waste Management. However, government-managed EPR funds seems to go against the purpose of EPR schemes, which is geared towards industry management and self-regulation. The EPR tax has thus received criticism from industry representatives, especially since National Treasury does not seem to provide for ring-fencing of the incoming funds (Karcher, interview, 2017). This highlights the separate issue of the lack of trust that the industry has in the SA government in allocating and distributing funds towards industry development. Furthermore, there were concerns regarding the additional administrative costs associated with the WMB who are meant to disburse funds, monitor and evaluate the implementation of the multiple IndWMPs (GreenCape, 2018).

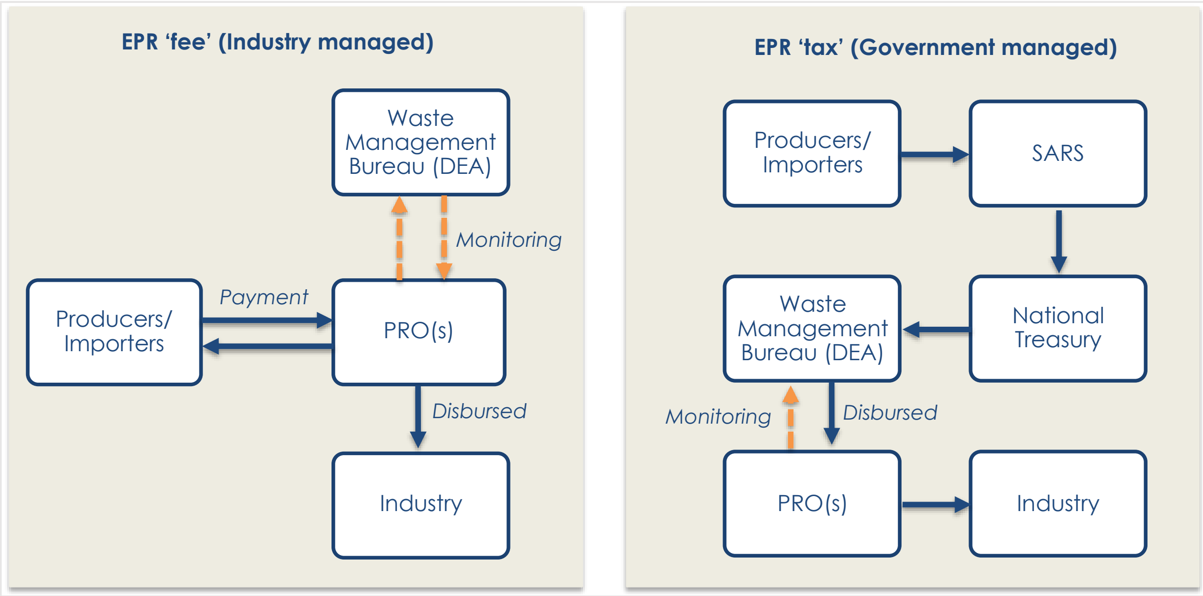

Figure 15: EPR fund management options as proposed in the National Pricing Strategy for Waste Management (adapted from E-waste Recycling Authority, 2018b)

In principle, EPR schemes would provide financial support to waste recyclers in handling negative value fractions as well as encourage investment into recycling technologies. While the new IndWMP for the waste tyre industry is awaiting approval, as well as the call for plans from the paper and packaging, electrical and electronic equipment, and lighting industries is underway, the success of EPR schemes in SA is yet to be determined.

The economic approach used in the National Pricing Strategy for Waste Management dis-incentivises landfill disposal as the primary waste management practice in SA through upstream and downstream instruments. Material and product taxes will be charged to resource extraction and product manufacturing activities, while disposal taxes and volumetric tariffs will be charged to waste generators (DEA, 2016b). These taxes force industry to invest in alternative waste management strategies, thereby investing in research and development, while adjusting to these new taxes. However, this may prove financially challenging for smaller businesses. Financial incentives to businesses may have been a more fitting strategy according to Mr Burnell, a partner at Fasken Martineau, a commercial law and litigation firm in SA (Breytenbach, 2015). Yet again, this displays the lack of integration and engagement of government initiatives for industry development with key stakeholders.

Overall the waste management sector in SA has gone through an evolution via the different stages discussed in this section. From its initial stages of landfilling most waste streams to the development of regulations for design and maintenance of landfills as well as the assessment of wastes allowed to enter different types of landfills. Thereafter, recycling and alternatives to landfilling began entering the waste legislation framework. This was followed by increased regulations regarding waste management monitoring and evaluation through NEMWA and NEMWAA.

SA now finds itself entering the era of EPR and IndWMPs for e-waste, waste tyre, paper and packaging, as well as lighting equipment industries. This current stage provides the perfect opportunity for industries to align and work together with government initiatives and policies towards a common goal – towards a secondary resource economy.

The next section will take a further look into the development of the e-waste industry in SA.

4.2 Developments in the South African E-waste Industry

The e-waste industry forms part of the waste management sector in SA. It is largely influenced by the legislative environment as mapped out in the previous section. To complement this, significant events were highlighted specifically linked to the e-waste industry. Such events include SA's ratification of the Basel Convention, SA's involvement in the Swiss E-waste Program, the election of the E-waste Recycling Authority (ERA) as a PRO, and the call for IndWMPs. These events are illustrated in Figure 16 and are thereafter elaborated on in subsequent sections.

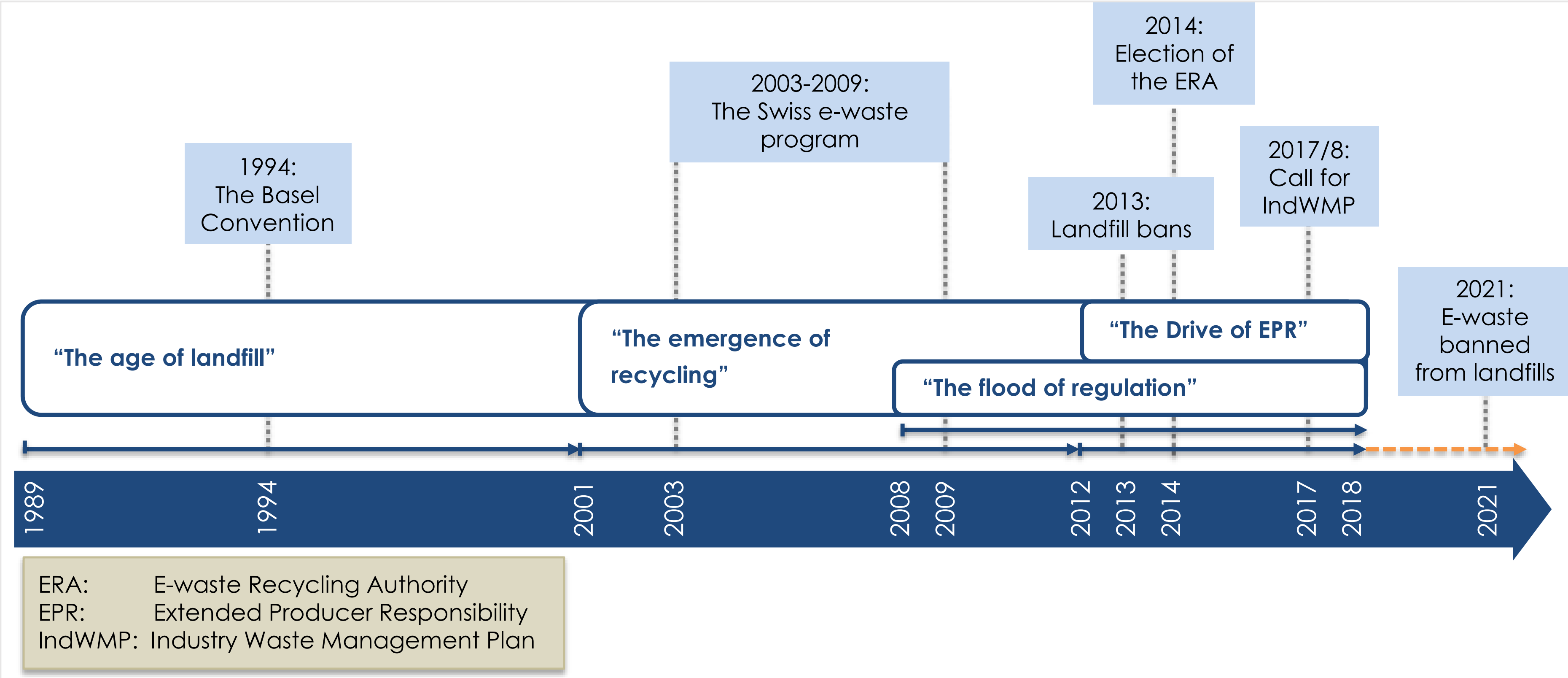

Figure 16: Significant Developments in the South African E-waste Management Industry

4.2.1 Early Beginnings: The Basel Convention

The United Nations developed the 'Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal' in 1989, hereinafter referred to as the Basel Convention. This international convention was developed in response to unregulated hazardous waste exports, including e-waste, from developed nations to developing nations. E-waste was traded under the guise of, and alongside second-hand electronic goods, which encouraged informal trade markets as well as crude recycling of e-waste in the affected nations. This resulted in serious health and environmental concerns together with negative social impacts including child labour. Some of the affected nations include India, China, Ghana and Nigeria (Mihai & Gnoni, 2016).

The Basel convention set the precedent for international hazardous waste legislation and guidelines with an emphasis on localized responsibility for the management of hazardous wastes where it is generated. Although SA was not directly affected by the e-waste dumping trend, there have been reported instances of illegal imports of e-waste into SA (Dittke, 2009; Lawhon, 2013). Furthermore, e-waste is suspected to be used to disguise illegal exports of precious metals out of the country (Independent minerals industry consultant, informal discussion, 2017). This, therefore, illustrates the need for legislation such as the Basel Convention.

SA became a signatory to the Basel Convention in 1994. According to Dittke (interview, 2018), the Basel Convention does not completely prohibit transboundary movement of hazardous waste but provides a means to control it. It requires consent from both importing and exporting countries before the trade can be made. This further aligned SA's waste legislation to international standards. Other examples of international e-waste legislation are listed and described in Table 13.

The EU WEEE Directive is the most widely known and referenced international legislation due to its comprehensiveness, covering the entire life cycle of EEE and WEEE. This directive is implemented through EPR or free take-back schemes, as well as influence product design and manufacturing towards more environmentally friendly alternatives. Furthermore, additional legislation to minimise the use of hazardous materials in EEE design and manufacturing is enacted through the RoHS Directive (Mihai & Gnoni, 2016).

Table 13: Examples of International E-waste Legislation (Dittke, 2009; Mihai & Gnoni, 2016; Baldé et al., 2017)

Country/ Region	Legislation	Overview
EU Countries	EU WEEE Directive, 2012	• Promotes design and manufacture for recycling and reuse of components and materials • Free take-back system
	Restriction on Hazardous Substances in EEE Directive (RoHS), 2011	• Promotes environmentally friendly materials used in design & manufacturing; • Prohibits the use of certain hazardous substances such as mercury, lead, etc.
Switzerland	Swiss Ordinance on the Return, the Taking Back & the Disposal of EEE (ORDEE), 1998	• Ensures e-waste does not end up in municipal collection systems through a free producer take-back scheme • Ensures awareness of consumers.
United States of America (USA)	'National Strategy on Electronics Stewardship' (NSES), 2011	• No national legislation in effect; each state has its own regulations; • However, the NSES aims to improve product design & the national e-waste management system
Japan	Law for the Promotion of Effective Utilization of Resources (LPUR) 2001	• Manufacturers & importers must organize the take-back system for EEE
Ghana	Hazardous & Electronic Waste Control Act, 2016	• Prohibits imports and exports of e-waste, • Provides for the registration of manufacturers, importers, and distributors of e-waste • Establishment of an e-waste management fund financed by manufacturers, importers, and distributors
India	E-waste (Management) Rule, 2016	• Mandates EPR for collection and financing of e-waste recycling

The EU WEEE Directive is e-waste specific and binds all the EU countries to adhere to it. This blanket legislation provides uniformity across the region and seems to be ideal for e-waste industries, given the well-organised and developed e-waste industry in EU countries. However, the directive cannot be read in isolation, as each country within the EU will have its own legislation pertaining to e-waste or hazardous wastes in general.

Other pieces of legislation are similar to the EU WEEE Directive, as is the case for Japan, in tits Law for the Promotion of Effective Utilization of Resources (LPUR). The Swiss Ordinance on the Return, the Taking Back & the Disposal of EEE (ORDEE) also emphasises the need for take-back schemes and consumer awareness regarding e-waste recycling and disposal. However, it lacks regulations for the design and manufacturing of EEE products.

The USA does not have any e-waste specific legislation enforced nationwide, instead each state has its own regulations. However, the National Strategy on Electronics Stewardship (NSES) aims to improve EEE product design and the national e-waste management system. Overall, international legislation incorporates two major categories: (i) EPR or free take-back schemes, and (ii) sustainable design and manufacture of EEE products.

Furthermore, there is an increasing number of developing countries, and countries affected by the 'e-waste dumping' trend enforcing e-waste legislation similar to the Basel Convention. This is present in countries such as Ghana and India. These pieces of legislation also incorporate both an EPR based scheme as well as financial systems for e-waste management.

In support of existing legislation, the recently published "Technical Guidelines on Environmentally Sound E-Waste Management for Collectors, Collection Centers, Transporters and Final Disposal in Ghana" developed by the Environmental Protection Agency (EPA), with support of the project Sustainable Recycling Industries (SRI), funded by the Swiss State Secretariat for Economic Affairs (SECO), provides a unique and necessary approach. These guidelines have been developed from a technical perspective and reviewed by a wide network of stakeholders. The purpose is to provide e-waste industry operators with technical guidance based on international standards and best practices (Environmental Protection Agency, 2018). This type of industry knowledge combined with government support is ideally what the industry needs to promote safe and effective e-waste management.

According to the Global E-waste Monitor Report for 2016, it was discovered that 34% of the world population was not covered by e-waste legislation (Baldé et al., 2017). The lack of e-waste legislation leaves countries vulnerable to bad management practices as well as informal and crude recycling and handling activities. In these countries, e-waste is most likely treated the same as general waste even though it has environmental risks (Mihai & Gnoni, 2016; Baldé et al., 2017).

Although SA does not have any e-waste specific legislation, it does have extensive hazardous waste legislation which includes e-waste. The downfalls of this is the blanket regulations on all types of hazardous wastes, even though there are different risks involved when handling the several types of hazardous waste. Perhaps technical guidelines in the form of norms and standards for industry operators, similar to that formulates in Ghana, is the next step for SA.

As previously mentioned, SA is heading towards an EPR based e-waste management system through the IndWMP. This reflects one of the trends in international legislation. However, SA cannot do much in terms of product design and manufacture due to the lack of a local EEE manufacturing industry. Although this aspect could be implemented through regulations or guidelines controlling the EEE imports into the country.

Both SA's e-waste management framework, as well as the operation of the industry, has been affected by international influence. The first international intervention is the country's participation in the Swiss Global E-waste Program (SGEP). This will be explored in the next section.

4.2.2 International Intervention: The Swiss Global E-waste Program

The e-waste recycling industry seemed to have gained traction during the "Emergence of Recycling" stage alongside other recycling initiatives in SA. The documentation thereof started in the early 2000s as a consequence of the international interest SA gained in being selected as part of the Swiss Global Knowledge partnerships in the e-Waste Recycling program, or the Swiss Global E-waste Program (SGEP) for short, together with India and China. The program was initiated in 2003 by the SECO and executed by the Swiss Federal Laboratories for Materials Testing and Research (EMPA).

The objectives of this program were to assess the status of e-waste management in emerging economies, design and implementation of improvement strategies, as well as facilitate international knowledge sharing (Widmer, Schluep & Denzler, 2008). This program brought about various research studies and pilot projects (Finlay, 2005; Widmer & Lombard, 2005; Bondolfi, 2007; Laffely, 2007; Schluep et al., 2008; Widmer, Schluep & Denzler, 2008). Using surveys, interviews, site visits and document reviews, these studies provided a comprehensive overview of the country's e-waste sector over the period of 2003-2009. It involved the participation of manufacturers, collectors, recyclers, researchers, as well as non-governmental organisations (NGOs) in the e-waste industry.

It should be noted that the e-waste recycling industry has existed long before the program. The main e-waste recycling companies in SA are listed in Table 14 in order of commencement of e-waste activities. Furthermore, the distinction between e-waste as a primary, secondary or equal (50:50) business activity is also listed. However, this list does not include all the companies that perform e-waste recycling activities in SA. An interactive map of all the e-waste recyclers that are members of the e-Waste Association of South Africa (eWASA) is shown in Figure 17, as available on the eWASA website (eWASA, 2019).

The earliest existing e-waste industry included recyclers such as Universal Recycling Company (URC), who indicate to have been in the business for more than 30 years (Universal Recycling Company, 2015), Desco Electronic Recyclers, founded in 1992 (Desco Electronic Recyclers cc, 2018a), and Sindawonye Granulators and Processors, founded in 1997. All three of these companies are located in Gauteng province, where one could say the e-waste collection and recycling hub of SA was born. However, e-waste was and is only a secondary business activity for URC and Sindawonye, while other scrap metal handling forms the primary activity. Other early e-waste recyclers include Computer Scrap Recycling, Just PCs and Indalo Resources, formed in the early 2000s.

Table 14: Commencement of E-Waste Activities as a Secondary, Primary or Equal Business Activity for a List of Companies in South Africa (adapted from Lydall, Nyanjowa & James, 2017)

	Company	Commencement of Operations	Commencement of E-waste Activities	E-waste as Primary Activity	E-waste as Secondary Activity	E-waste as Equal Business Activity (50:50)
1	Desco Electronic Recyclers	1992	1992	x		
2	Universal Recycling Company	1992	+30 years ago		x	
3	Sindawonye Granulators & Processors	1997	1997		x	
4	Computer Scrap Recycling	1998	early 2000s			x
5	Just PCs	2001	2001		x	
6	Indalo Resources Ltd	2003	2003	x		
7	Rand Refinery	1920	2004		x	
8	Inca Metals	2007	2007		x	
9	Virgin Earth	2008	2008	x		
10	Reclite	2009	2009	x		
11	Sims Recycling	2009	2009	x	x	
12	New Reclamation Group	1980	2010		x	
13	SmartMatta (Re-Ethical)	1998	2010		x	
14	Waste Plan	2004	2010		x	
15	Africa E-Waste	2011	2011	x		
16	Cape E-Waste	2012	2012	x		
	Company	Commencement of Operations	Commencement of E-waste Activities	E-waste as Primary Activity	E-waste as Secondary Activity	E-waste as Equal Business Activity (50:50)

17	**Tshwane Electronic Waste Company**	1995	2012		x	
18	**Sibanye Recycling Ltd**	2010	2012			x
19	**E-Waste Africa**	2012	2012	**x**		
20	**Effortless Computer Recycling**	2012	2012		x	
21	**Electronic Cemetery**	2010	2013	**x**		
22	**Bolunga Electronic Waste Ltd**	2014	2014		x	
23	**E-waste Technologies Africa**	2000	2015		x	
24	**SA Precious Metals**	2000	2015	**x**		
25	**Javco**	unknown	unknown		x	
26	**Metrex**	unknown	unknown		x	

Key:

Shaded blocks refer to companies whose e-waste activities commenced more than one year after the business was founded

All companies listed below the bold line commenced their e-waste activities after 2003

Figure 17: Screenprint of the interactive map available on the eWASA website

The Swiss visitors highly commended the existing "state-of-the-art" material separation technologies, which was presumably that of URC, Desco and Sindawonye (Widmer & Lombard, 2005). This suggests that SA's technologies at the time were on par with the Swiss standard.

Most e-waste recyclers listed in Table 14 were formed after 2003, eight of which were companies with e-waste activities as its primary business. A further eight waste management companies that existed before 2003, initiated e-waste handling activities after 2003. Seven of which only initiated e-waste activities from 2010 or later (Lydall, Nyanjowa & James, 2017). This illustrates the infancy of the e-waste industry in SA, particularly at the time the SGEP commenced.

Although there were e-waste companies that formed post the commencement of the SGEP, there is no evidence that the program resulted in any e-waste processing technology investments. Interestingly, interventions in terms of local end-processing and beneficiation were also not thoroughly covered in the SGEP research studies. This is particularly relevant due to the minerals extraction and processing economy here in SA. This may be due to the lack of experience thereof from a Swiss perspective. Alternatively, the adoption of the 'Best-of-2-world's' philosophy may have been encouraged, as advocated through EMPA affiliations with the associated research. As outlined in Section 2.4.1, the philosophy encourages manual dismantling and pre-processing occurs in developing countries in preparation for exporting high-quality value streams to sophisticated end-processing operations in developed countries (Wang et al., 2012).

Nevertheless, the Swiss advocated for greater emphasis on extending product lifespans through the refurbishment and re-use of e-waste devices before recycling thereof. This is in line with the CE framework as well as the waste hierarchy, as discussed in Section2.1. Additionally, the use of Opensource software was encouraged to allow extended use of older equipment to run on updated operating software (Widmer & Lombard, 2005).

In addition, the Swiss ideology of e-waste management systems and structures infiltrated the South African industry. This is evident in the establishment of the first formal e-waste management structure in SA, namely the eWASA. The eWASA is a coalition of manufacturers, recyclers, refurbishers and NGOs (Ecroignard, 2006; Lawhon, 2012). It was formerly referred to as an e-waste working group before it was officially recognised as an NGO in 2008, with the assistance of the Swiss team.

It is suggested that non-governmental management structures such as these play a co-regulatory role alongside the government in policymaking, regulation and monitoring (DEA, 2011). Therefore, they would be a key role player in driving the SA e-waste industry forward. This could be particularly useful in bridging the gap and consolidating government and private sector agendas.

The vision for eWASA was for it to develop a take-back system for e-waste similar to the Swiss Trade Association of the Information, Communication & Organisation Industry (SWICO) (Widmer & Lombard, 2005). The SWICO model is based on an EPR system, however, the electronics industry in SA is based on imports from international companies. Therefore the 'producers', in its conventional sense, are located outside of the jurisdiction of the country. This may be one of the reasons why EPR has yet to be successful in SA.

One other coalition, initially named Recover-E Alliance (now renamed to SAEWA), formed soon after the eWASA, as a result of a pilot project in Maitland, Cape Town, funded by Hewlett-Packard (HP) as part of their international EPR initiative (Schluep et al., 2008). It is now known as the Southern African E-waste Alliance (SAEWA). The pilot project aimed to test the feasibility of a material recovery facility that conducts refurbishment, dismantling, and waste-to-art activities. Furthermore, it was to act as a blueprint for future projects to raise community awareness, create job opportunities and promote entrepreneurship in communities in developing countries (Schluep et al., 2008). However, the project proved unprofitable overall due to the fluctuating prices of e-waste value fractions, the lack of local and international markets for waste-to-art products, and the high operating costs (Karcher, interview, 2017).

Although unsuccessful, this is the first documented EPR initiative by an Original Equipment Manufacturer (OEM) in SA. No further projects seem to have arisen from this, particularly none initiated by HP. However, the lessons learnt, and experience of the pilot project is useful for existing e-waste businesses. Karcher (interview, 2017) who was assigned the independent third-party evaluation of this pilot project readily shares her experience from the project with members of SAEWA and advises them accordingly.

An additional outcome of the SGEP was the e-waste workshop at WasteCon 2008 held in Durban, SA. Delegates of this workshop were signatories to what is called the Durban Declaration, an agreement aimed at developing National Action Plans (NAP) for sustainable e-waste management systems in participating countries. The signatories of the declaration include representatives from e-waste projects in Morocco, Senegal, Kenya, Uganda, Nigeria and SA (EMPA, 2008). This declaration is in alignment with the memorandum of understanding of the StEP-initiative which was established as the new global platform to further the initial work of the SGEP (Widmer, Schluep & Denzler, 2008).

It is unclear whether the proposals presented in the declaration had any influence on SA policy today. However, a proposed NAP for the e-waste industry in SA is promising through the development of an integrated IndWMP for e-waste. This will be further discussed in the section to follow.

4.2.3 Industry Waste Management Plans and the E-waste Recycling Authority

An initial announcement of the intention to call for IndWMPs by the Minister of the DEA as early as 2014, spurred on the formation of the E-waste Recycling Authority (ERA). The ERA is the very first PRO for the implementation of the IndWMP for the electrical and electronic equipment industry. The ERA steering committee (SteerCom) was formed by delegates who attended the e-waste Consultative Conference convened by the DEA in 2014. The SteerCom comprises of representatives from the ICT and white goods manufacturing sector, small and large e-waste recyclers, as well as other industry associations along the value chain (E-waste Recycling Authority NPC, 2018b). The ERA's mandate is to develop the e-waste IndWMP as envisioned by the NEMWA and NEMWAA. This allows industries the opportunity to implement EPR schemes and levies to subsidise disposal of non-viable fractions.

The DEA, which is the legislative authority for waste management in SA, not only holds an environmental stewardship agenda but also perceives e-waste recycling as an enterprise development and job creation opportunity, thereby promoting the secondary resource economy (DEA, 2015c). These agendas are to be fulfilled through the IndWMP for the e-waste industry via an EPR scheme to promote and fund industry growth and development. This twofold agenda provides a potential conflict in how the waste sector is governed. Ideally, economic gain would come secondary to sustainable waste management practices and environmental stewardship.

An official call for IndWMPs by the Minister of the DEA was posted in December 2017, for the paper and packaging, electrical and electronic, and lighting industries. This requires input from all producers (any person engaged in the commercial manufacture, conversion, refurbishment or import of new and/or used materials) which includes e-waste refurbishers. These plans are to be developed by industry, either collectively in a joint plan, or individually. Multiple plans can be developed and submitted, and multiple plans or a single plan can be approved by the minister. Thus, the ERA is not the only body that can submit a plan, and therefore not the only plan that may be approved.

Previous calls for plans have been rejected by the three industries involved, and consequently withdrawn due to various concerns which thereby delayed the process by three years. According to Karcher (interview, 2017), these concerns included: (i) the short timeframe given for plans to be submitted, (ii) the definition of 'producer' in terms of the EPR scheme, as well as (iii) the fund management options. The timeframe for submission of plans was initially 30 days, however, this was soon revised and an agreed date for submission was set for September 2018.

The second concern, regarding the definition of 'producer', is specifically complex for SA as an importer of finished electrical and electronic goods. Given the continuous and rapid decline of any form manufacturing in SA over the last few years and as submitted by the DTI annual statistics, the 'producer' thus lies outside of SA. The packaging industry was especially concerned as they believe the international brand owners should rather be responsible, as opposed to the designers, manufacturers or converters in SA (Karcher, interview, 2017).

In terms of the e-waste industry, the producer would most likely be the importers and retailers of electronic goods. The ERA highlights this in their definition below:

> *"Producer" means any person or category of persons or a brand-owner who is engaged in the commercial manufacture, conversion, refurbishment or import of new/or used electrical and electronic equipment which is intended for distribution in the Republic of South Africa".* – E-waste Recycling Authority NPC (2018)

This definition includes manufacturers and importers of EEE which is intended for distribution in the country. The largest trade bodies of EEE, the Information Technology Association (ITA) and the South African Domestic Appliances Association (SADA Association), are members of the ERA. This ensures that these producers have been involved in the development of and discussion around the IndWMP.

Interestingly, the ERA's producer definition also includes refurbishers. The position of refurbishers in the value chain is blurry as they partake in product distribution and resale to consumers similar to retailers. However, they also generate e-waste as part of their repair service offering and form part of the waste management sector.

Another cause for concern is the appropriate management of EPR funds as previously elaborated on in Section 4.1.4. This issue has been raised by both the waste tyre and packaging industries, and the conversation now continues with the e-waste industry. Given that fund management is the main concern for both government and industry, there should be measures in place in the IndWMP to prevent any conflict in this regard. The DEA's solution is to employ another government body, the WMB, to specifically deal with the distribution of funds after collection by National Treasury. Karcher (interview, 2017) believes that the role of the WMB overlaps with that of industry and may cause potential conflicts of interest. There is thus an underlying political issue of confusion in power and wealth, and the distribution thereof.

Furthermore, Karcher (interview, 2017), expresses concerns that the DEA's initially intended agenda is shifting from enforcing an EPR levy to subsidise recyclers for non-viable or negative value e-waste fractions, towards promoting job creation and enterprise development opportunities. She believes that the economic motive is driven by the DST's R25,2 billion valuation of the industry's potential (DST, 2014). In her opinion, government is overestimating the economic and employment potential of the waste economy and thereby pushing the job creation agenda.

> *"It [the DEA's intention for the IndWMP] moved entirely away from developing this levy to benefit the recyclers to take care of the non-viable fractions to 'Where's the job creation?' 'Where's the enterprise development?' And we feel we've been put under undue pressure in those areas because our plans are actually first and foremost to compensate the recyclers for non-viable fractions."*
>
> *– Karcher, interview, 2017*

Karcher (interview, 2017), further explains that the ERA SteerCom feels somewhat pressurised to put more focus on job creation and enterprise development due to the DEA's change in focus. She adds that this resulted in the ERA's proposed plan that earmarks 26% of the funds to be allocated for the recycling subsidy, and 36% to enterprise development, in order to accommodate the government's agenda. The total budget of the plan has envisioned to be approximately R0.5 billion per year. The complete budget breakdown is illustrated in Figure 18 (E-waste Recycling Authority, 2018a).

Besides enterprise development and recycling subsidies, the ERA has planned for 12% of the budget to go towards technology development and research. This is a positive indication that the IndWMPs may assist in the development of the local end-processing sector for e-waste.

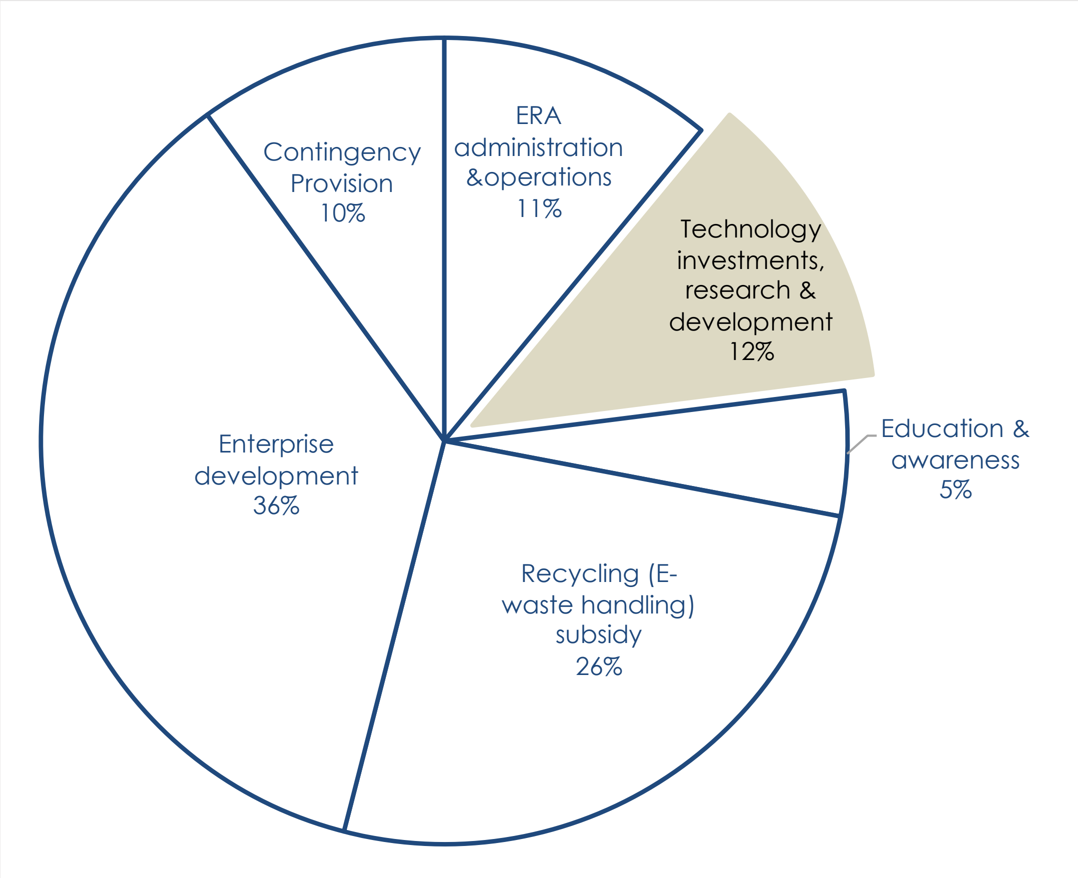

Figure 18: Pie chart showing the breakdown of the ERA's IndWMPs first-year budget (adapted from E-waste Recycling Authority, 2018a)

Concerns regarding other bodies submitting plans have also arisen, with a somewhat political nature. Both chairmen of SAEWA and eWASA, two voluntary e-waste management organisations, were part of the ERA SteerCom, however, eWASA's chairman withdrew from the committee in 2017 (Karcher, interview, 2017). A total of five e-waste IndWMPs have since been submitted for review as of September 2018, including one led by eWASA (the SAWEEEDA NPC plan) and one by the ERA (DEA, 2018). The outcome of whether one or all plans will be approved will be announced in 2019 after a lengthy selection process.

Given the historical distrust between the government and industry bodies regarding power and wealth, many political issues have arisen upon the forced cooperation ensured by the IndWMPs. In order to ensure the successful implementation of the e-waste IndWMP to promote industry development, trust and relationship building will be key.

Besides interventions presented by the IndWMP to divert waste from landfill, additional legislation to ban certain waste streams from landfill has been promulgated. This will be discussed in the section to follow.

4.2.4 E-waste Banned from landfills

The "National Norms and Standards for Disposal of Waste to Landfill" includes the prohibition of certain waste streams from being landfilled according to certain time frames in an attempt to move away from landfilling (Department of Water and Environmental Affairs, 2013). The implementation of these disposal restrictions could indicate the nearing conclusion of the "Age of Landfill".

Dittke (interview, 2018) explains that the notice document was published in August 2013 and outlines that lighting equipment will be banned from landfills within three years of the notice and was thus enforced as of August 2016. Lighting equipment waste generators are thus forced to pay for recycling services from lighting recyclers such as Reclite and E-waste Africa. The landfill ban has thus increased recycling rates of lighting equipment in the country thereby fulfilling the purpose (Lydall, Nyanjowa & James, 2017). However, some lighting equipment, particularly from households still end up in municipal landfills, if not intercepted by waste pickers.

For other e-waste fractions and batteries, the timeframe listed was eight years, which means that these streams will be officially banned from landfills as of August 2021. This timeframe poses a huge challenge for the industry to successfully implement the IndWMPs and improve collection and recycling rates by then. Once the ban comes into effect as well as the initiatives presented by the IndWMP, e-waste recycling rates should increase. E-waste generators would be forced to ensure their e-waste is properly recycled and may face increased waste management costs. Furthermore, recyclers would benefit due to the higher demands and subsidies received through the IndWMP EPR scheme, which would ultimately be at the expense of consumers through product taxing.

An unwanted consequence of this landfill ban may be an increase in the number of cases of illegal dumping by waste generators to avoid the costs of recycling. However, recycling subsidies provided through the IndWMP is meant to prevent this from happening.

4.3 Conclusion

As the waste management sector in SA concludes its 'Age of Landfill', further develops its recycling capacity, and matures into the ideals of regulation and EPR schemes, one begins to wonder, what is the next stage for waste management in SA? And even more so, what is the next stage for the e-waste recycling industry? Would it be the coming of a secondary resource economy?

In order for this to happen, integration and investment into suitable technologies, economic strategies, legislation as well as inclusion and commitment from all stakeholders is required. The next chapter takes a deeper look into these aspects.

5 Setting the Scene: South Africa's WEEEcosystem

An ecosystem is an interconnected system made up of living and non-living constituents governed by the laws of nature. The e-waste industry resembles an ecosystem – the WEEEcosystem – as it is made up of interconnected and interdependent living – stakeholders involved – and non-living parts – resources, money, and infrastructure. There is a given set of governmental laws regulating the industry but also social laws which govern the WEEEcosystem. These laws, stakeholders, resources and infrastructure and their role within the complex network of SA's WEEEcosystem, will be described in this chapter.

Firstly, the volumes and flows will be investigated to both define the extent of the problem and to plan for the future of its management. Thereafter the e-waste value chain will be discussed in terms of activities, technologies and role players involved. The legislative framework will then be outlined and finally, a glance into current and prospective e-waste management structures that will promote the establishment of a secondary resource economy for e-waste in SA.

5.1 E-waste Quantities & Flows

Data quantifying the amount and main sources of e-waste generated and recycled is important for effective e-waste management systems through industry development and planning (Godfrey & Scott, 2010). This includes informing technological infrastructure design and feasibility, as well as identifying suitable product markets. However, there is a lack of reliable and consistent data available as the industry (Bob et al., 2017; Department of Environmental Affairs and Development Planning, 2018). This is attributed to the infancy of the industry and therefore that of its information systems (Lydall, Nyanjowa & James, 2017).

5.1.1 E-waste Databases & Reporting in South Africa

The South African Waste Information System (SAWIS) is a national repository for waste information. SAWIS was implemented on a voluntary basis since 2006, due to the lack of mandatory waste information regulations at the time. Therefore, the national dataset is both incomplete and unverified as only a fraction of waste companies were reporting regularly (DEA, 2012).

The national waste information regulations were put forward in 2012 – six years after the implementation of SAWIS (*NEMWA, Act No. 59 of 2008. Regulation*, 2012). However, these regulations only came into effect in 2014. Therefore, waste information reporting was mandatory only for the last four years (Godfrey & Oelofse, 2017). Furthermore, compliance with or enforcement of these regulations remains an issue in producing accurate waste information for the country (DEA, 2012).

Existing provincial repositories for waste information include the Integrated Pollution and Waste Information System (IPWIS) for the Western Cape; and the Gauteng Waste Information System (GWIS). These repositories were developed before the SAWIS and were planned to be aligned with the SAWIS in 2009/10 (South African Waste Information Centre, 2016).

An Environmental Risk Officer from an institution of higher education (interview, 2017) explains that institutions in the Western Cape are required to report all hazardous and general waste generation volumes through IPWIS every month. The reporting of waste volumes is conducted both internally for the institutional records, as well as externally for municipal records.

The reporting of waste volumes on IPWIS initially only included medical and biological risk waste. In 2015, hazardous chemical wastes were also included in the reporting, and only in 2016 did general wastes need reporting. The Environmental Risk Officer (interview, 2017) further explains that the general waste data currently reported at the institution is not completely accurate even after two years of reporting. This implies that institutions may take a couple of years to properly establish a waste management information system. Furthermore, the accuracy of the data is compromised during the initial stages of its establishment.

Additionally, institutions are faced with internal pressures and often cannot keep up with increasing expectations regarding waste management legislation. An example of this is illustrated in the quote below.

> *"It's just in the last year or so in Properties and Services [department at the institution], we've been running around with our heads chopped off. I mean, all of our portfolios have expanded somewhat and just running to a standstill quite often. And also,*

government demands have been increasing, which is good. It's a good thing, but it just makes your life a bit more difficult."

- Environmental Risk Officer (interview, 2017)

Moreover, waste management is not given high priority in terms of resource allocation in institutions, leaving them understaffed and/or underfunded. This is one of the main barriers to good waste management practices in private industry (Godfrey, Scott & Trois, 2013). Private waste companies and municipalities experience these constraints specifically for data collection and reporting, according to Godfrey & Scott (2010).

Institutions are required to contract registered waste service providers for their waste management needs. Ideally, volumes reported by generators will tally up with volumes reported by registered waste contractors or handlers. This could potentially be successful with larger businesses or institutions. However, smaller businesses and household generators do not use the IPWIS system, and thus will not report their generated volumes. Furthermore, their waste will likely end up in municipal landfills or waste drop-off sites, which is currently not recorded in the IPWIS system.

The purpose of the waste information within institutions, other than mandatory reporting is primarily for anticipating collection logistics (Environmental Risk Officer, interview, 2017). However, there is little evidence of the conversion of this waste information, for e-waste specifically, into changes within the institution. This is due to the relatively low and erratic e-waste generation volumes, making any efforts futile. An additional purpose for waste information is to provide a chain of custody or traceability of e-waste. This is useful for legal audits, preventing the trade of stolen goods, and for reporting the origin of materials recycled in the chain. The latter is used in 'closing the loop' initiatives.

Waste information in terms of generation and recycling rates remains a useful tool in assessing the industry and planning its development. However, it can only be useful if the information is accurate and complete. The next section will discuss the generation and recycling trends for the e-waste industry in SA.

5.1.2 E-waste Generation & Recycling Rates

As mentioned previously, there is no accurate and complete waste information dataset in SA, however, there are some reported estimates of generation and recycling rates for e-waste. Reported volumes and growth rates of e-waste generated and recycled in SA use different estimation methods and data sources. Some of these estimated values are reported in Table 15. The most recent estimates by Koekhoven (2015) and Baldé et al. (2017) agree on the volume of e-waste generated in SA which was over 320 000 tons in 2016. However, it is unclear whether the methods used to determine these values were similar.

Koekhoven (2015), reports a volume estimation obtained from an interview with Keith Anderson, the chairperson of eWASA. Anderson suggests that only 12 % of e-waste was recycled in 2015, which amounts to approximately 40 000 tons. This low recycling rate is attributed to the majority of e-waste being inaccessible as it is either in storage or ending up in municipal landfills, according to Anderson (Koekhoven, 2015). Furthermore, poor collection infrastructure, a poorly integrated collection network, high cost of transport, and lack of consumer awareness, all contribute to the inaccessible e-waste volumes (Finlay, 2005; Widmer & Lombard, 2005; Finlay & Liechti, 2008; GreenCape, 2018).

The recycled volume estimated by Anderson in Koekhoven (2015) is more than double the amount estimated to be recycled in 2015 by the 27 firms that participated in the e-waste technology landscape study (Lydall, Nyanjowa & James, 2017). This may be true as the companies participating in the study only represented a fraction of the total e-waste recycling firms in SA. Furthermore, assuming Anderson's claims are based on insights received from his 100+ members listed on eWASA's website; his estimation may be more representative of the industry.

Four years earlier, the DEA reported a much lower e-waste generation volume of only 64 000 tons in 2011. Reasons for this low estimation may be due to the old, incomplete and unverified data sources used, dating back to 2005 (DEA, 2012). Furthermore, the many variables such as population growth, increased accessibility, decrease in product lifespans and rapid advancements in technologies, resulting in increased consumer demand, can all explain the lower generation value compared to more recent studies.

Table 15: Estimates of e-waste generated per annum from different sources

E-waste Generated & recycled per annum (pa)	**Estimation method used**	**Sources**
15 000 - 30 000 tons generated in 2005, estimated to double in 10 years; more than 4 300 tons (15-30 %) recycled in 2004	Generated volumes based on interview source Ray Lombard, an environmental consultant. Recycled volumes based on amount handled by two out of the three major e-waste recyclers in SA at the time - Desco and URC; estimates for African Sky was not provided.	(Finlay, 2005)
64 045 tons generated in 2011; 11 % recycled	Based on existing waste data and population extrapolation estimates.	(DEA, 2012)
322 000 tons generated in 2015; 12 % recycled	Based on the information provided by Keith Anderson, chairperson of eWASA.	(Koekhoven, 2015)
17 773 tons recycled in 2015	Based on the amount of e-waste handled by 27 recycling firms participating in the research study.	(Lydall, Nyanjowa & James, 2017)
321 000 tons generated in 2016	Based on Comtrade databases of import and export volumes per country per year to calculate sales of EEE, which is then adjusted by the average product lifespan to calculate e-waste generated. See reference for detailed method description.	(Baldé et al., 2017)

Another six years earlier, Finlay (2005) reports that e-waste generated in 2005 was more than half than that reported by (DEA, 2012) based on an interview source, Ray Lombard, an environmental consultant. Lombard estimated that the generated volume will only double in 2015. However, if his initial estimation was correct, it happened twice as fast as his prediction. This would further confirm the rapid growth rates of e-waste generation.

Interestingly, the DEA reports that 11% of e-waste generated was recycled in 2011, similar to Anderson's estimation of 12% in 2015. Even though the percentage of e-waste recycled remains constant from 2011 to 2015, the volumes recycled has increased as the e-waste generated has increased. So, even though the recycling capacity is increasing, more aggressive interventions are needed to increase the relative percentage of recycling more rapidly.

E-waste storage is a major challenge in SA. The DEA recommends that quantification processes for e-waste storage and generation should be in place in organizations (DEA, 2015a). Furthermore, in order to unlock government ICT legacy volumes, as part of the National Development Plan, Operation Phakisa proposes to introduce a government-wide e-waste asset management system (GreenCape, 2018). However, the release of legacy e-waste volumes may only provide a temporary influx followed by a decline in the accessible volumes. This phenomenon has been experienced by many recyclers interviewed upon gaining new clients, accessing a new area, or receiving new tenders (Cape E-waste, interview, 2017; NC Electronix, interview, 2017).

Examples of this phenomenon can be attributed to hardware upgrades such as the changeover to fibre optic cables in the telecommunication industry to improve internet capabilities. Additionally, certain devices have a limited lifespan which will call for an upgrade which can be predicted. Examples include universal upgrades in software such as that in upgrading from Windows XP to the later versions, or license expiration of International Business Machines Corporation (IBM) software every three years, which requires an upgrade of hardware for many server and mainframe facilities (Cape E-waste, interview, 2017).

As previously mentioned, increasing access to e-waste would be the main contributor to increasing recycling rates. To understand how greater volumes could be accessed, besides those currently in storage, the geographic accessibility of e-waste volumes should be understood.

5.1.3 E-waste Sources & Flows

The geographic scope of e-waste assessments in SA has mainly focused on Gauteng and Western Cape. This is because most of SA's recyclers and sources of e-waste can be found in these provinces, thereby forming e-waste hubs or regional centres. Gauteng and Western Cape provinces are the primary sources of e-waste in SA, followed by Kwa-Zulu Natal and the Eastern Cape. These provinces make up between 50-90% of inputs for the 27 firms in the study by Lydall, Nyanjowa & James (2017) in 2015.

Provinces such as Northern Cape, Free State, Mpumalanga and Limpopo are considered secondary sources of e-waste (Lydall, Nyanjowa & James, 2017). This could be linked to the lower population densities and industrial development of these provinces. Consequently, there are limited drivers for the development of an e-waste industry in those regions.

A visual summary of e-waste flows, and major input nodes in SA is depicted in Figure 19. The major nodes are shown in light blue, with varying sizes according to the percentage volume of e-waste handled in 2015. E-waste flows within SA is shown by the broken orange arrows.

Most of the e-waste in SA is generated and sourced locally. A total of 94% of e-waste volumes were sourced nationally, while 6% was sourced from Sub-Saharan African countries in 2015. These countries include Malawi, Mozambique, Namibia, Botswana, Swaziland, Tanzania, Zambia and Zimbabwe. However, these markets are considered highly variable (Lydall, Nyanjowa & James, 2017). According to Karcher (interview, 2017), SA e-waste recyclers have very little interaction with north and central African countries. These markets are most likely accessed by European e-waste recyclers.

However, illegal imports of e-waste under the guise of second-hand goods, is not uncommon in SA, as suggested in Lawhon (2013). These foreign volumes would probably land up in second-hand goods markets or the informal sector, and eventually, find their way into the e-waste value chain.

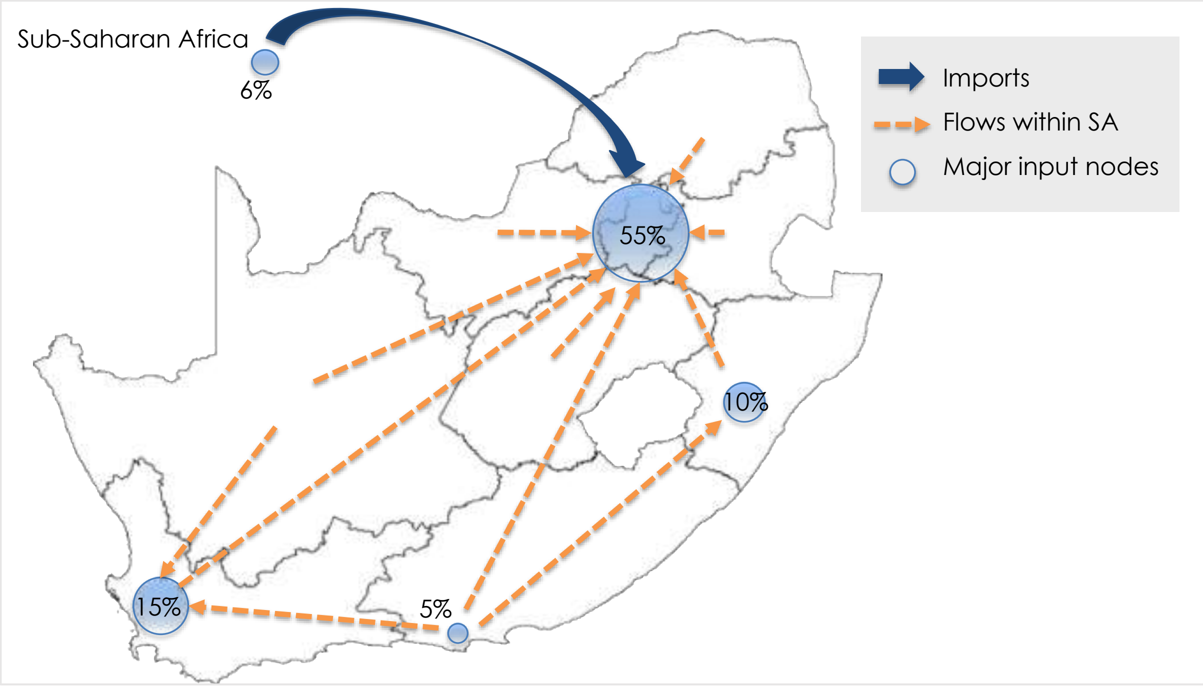

Figure 19: E-waste flows and major input nodes in SA (adapted from Lydall, Nyanjowa and James, 2017)

Recyclers in Gauteng generally source e-waste from all the provinces in the country, whereas those in the Western Cape only receives inputs from its neighbouring provinces, as depicted by the orange broken lines in Figure 19. This is most likely a result of the relative locations and ease of access in terms of transport logistics and costs.

5.1.3.1 E-waste Hubs

Gauteng was the major e-waste hub in 2015, handling 55% of the total e-waste handled by the 27 firms in the study by Lydall, Nyanjowa & James (2017). The Western Cape is the second-largest hub, followed by Kwa-Zulu Natal and Eastern Cape, handling 15%, 10% and 5%, respectively. These four provinces are also the main locations of the major e-waste recyclers in SA as shown in Table 16.

The top five companies handling the largest volumes of e-waste in SA in 2015 are namely, Desco, Sindawonye, URC, New Reclamation Group (NRG) and Sims. These five companies handle 78,9% of the total volumes processed by the 23 companies that participated in the previously mentioned study.

Table 16: List of e-waste recyclers and regional presence in South Africa in order of volumes handled in 2015 (adapted from Lydall, Nyanjowa & James, 2017)

	Company	Volume of e-waste handled in 2015 (tons)	Gauteng	Western Cape	Eastern Cape	Kwa-Zulu Natal	Northern Cape	Free State	Limpopo	North-West	Mpumalanga
1	Desco Electronic Recyclers	5000	X	x	x	x		x	x	x	x
2	Sindawonye Granulators & Processors	3000	X		x						
3	Universal Recycling Company	3000	X		x						
4	New Reclamation Group	1500	X	x	x	x	x	x	x	x	x
5	Sims Recycling	1500				X					
6	SA Precious Metals	728	X								
7	Cape E-Waste	500		x							
8	Reclite	400	X	x	x	x					
9	Africa E-waste	383	X								
10	E-Waste Africa	300				X					
11	Sibanye Recycling Ltd	300				X					
12	Computer Scrap Recycling	240	X			x					
13	Tshwane Electronic Waste Company	240	X								
14	Bolunga Electronic Waste Ltd	200			X						
15	Waste Plan	200	X	X		X		x			

	Company	Volume of e-waste handled in 2015 (tons)	Gauteng	Western Cape	Eastern Cape	Kwa-Zulu Natal	Northern Cape	Free State	Limpopo	North-West	Mpuma-langa
16	Inca Metals	60			X						
17	SmartMatta (Re-Ethical)	60	x	x		x					
18	Electronic Cemetery	44				X					
19	Virgin Earth	24		X							
20	Effortless Computer Recycling	20	X								
21	E-waste Technologies Africa	20			X						
22	Metrex	12		X							
23	Javco	2				X					

Table Legend:

Large recyclers handling more than 1000 tons of e-waste per year

Medium recyclers handling between 100-1000 tons of e-waste per year

Small recyclers handling less than 100 tons of e-waste per year

X Location of the companies' main operations

x Location of the companies' secondary operations

The volumes processed by these companies ranged from 5000 tons of e-waste per year to as little as 2 tons per year. The companies shaded in blue will be referred to as large recyclers; they are categorized as handling more than 1000 tons of e-waste per year. The companies shaded in orange are medium recyclers and are categorised as handling between 100-1000 tons of e-waste per year. Small recyclers handle less than 100 tons of e-waste per year and are shaded in grey.

Although Gauteng houses four out of the five largest recyclers in SA, it is not an ideal location in terms of imports and exports as it is a landlocked province. Therefore, provinces with major ports, such as the Western Cape and Kwa-Zulu Natal are more suitable in this regard.

Large recyclers in Gauteng would usually transport their shipping loads to Kwa-Zulu Natal for export. This may not be as accessible to smaller recyclers in the region; therefore they would be forced to find alternatives. A possibility would be to sell it to the larger recyclers; however, they may not get as good a price. On the other hand, smaller recyclers in the Western Cape, such as NC Electronix and Cape E-waste, do not have an issue with additional transporting to a port, as they are within a reasonable distance.

Sims Recycling, an international company with operations in SA, mentions that cross-boundary activities afford their clients standardized service delivery wherever they are located. Therefore, since their operations in SA only dismantles and prepares e-waste fractions for end-processing, hey likely ship goods from their regional operations in SA to perform end-processing elsewhere. This resembles the scenario proposed in the Best-of-2-worlds philosophy described in Section 2.4.1.

Some companies have a presence in multiple locations in SA, however, these are mainly concentrated in the major e-waste hubs, as previously mentioned. The location of the companies' main operations is marked by an (X) and that of the secondary operations is marked with an (x) in Table 16. Companies with satellite or secondary branches include Desco, NRG, URC, Sindawonye, Reclite, Computer Scrap Recycling, Waste Plan and SmartMatta. These are mainly large recyclers and processors, or large integrated waste contractors, while, small and medium recyclers tend to focus their activities is one province. The main reasons for companies operating in multiple locations are as follows:

i) to source more feed for its main operation, as is the case for Desco,

ii) it has high demand and low competition for its services in other locations, as is the case for Reclite,
iii) it is set up similarly in different regions, as is the case for NRG and integrated waste contractors such as SmartMatta and Waste Plan, or
iv) it is performing a different service in another location but still operating under the same larger brand, as done by Sindawonye.

Desco has a presence in eight out of the nine provinces in SA. This does not necessarily mean Desco has offices in all eight provinces. Rather, it has a total of 61 e-waste drop-off and collection sites all over the country, but its only processing operation is in Gauteng (Desco Electronic Recyclers cc, 2018b). Its wide collection network explains its high processing volumes and its title as the largest e-waste processor in SA. It should be noted that Desco used to have regional offices and recycling operations in both Western Cape and Kwa-Zulu Natal, however, those have both closed down due to liability risks (Karcher, interview 2017). The regional operation in the Western Cape is now operating as Cape E-waste, as one of the listed e-waste drop-off sites, and owned by former employees of Desco.

NRG is the only recycler with presence in all nine provinces, with 100 satellite branches. However, e-waste is only a secondary activity, as their primary business is in scrap metal trading. Similarly, URC and Computer Scrap Recycling has secondary activities along with e-waste recycling. For URC it is scrap metal recycling and for Computer Scrap Recycling it is refurbishment. Both companies have their main branch in Gauteng with smaller branches in one other major province, the former in Eastern Cape and the latter in Kwa-Zulu Natal. Furthermore, SmartMatta and Waste Plan are both large integrated waste contractors in SA. E-waste recycling is therefore only a secondary business activity. Their regional branches all perform similar operations in all their locations due to the nature of the business.

Sindawonye, on the other hand, is primarily an e-waste recycler, but its speciality is in large telecommunication equipment tenders with companies such as Telkom. Sindawonye's main branch is located in Gauteng while having satellite operations in the Eastern Cape. It merged with a ferrous recycler in the Eastern Cape as well as subcontracting a company, Thembani, as part of its corporate social responsibility.

Thembani recycles fibre optic cables and other reclaimed materials such as glass and plastic bottles.

Reclite also provides a speciality service and thus can afford to have a presence in more than one major province. It is the larger of the two lighting equipment recyclers in SA. It has a high demand for its services and thus has a presence in the four major provinces.

The owners of Cape E-waste suggest that Gauteng is a larger hub than the Western Cape because there are more commercial businesses in Gauteng, which provides a significant supply of e-waste. Furthermore, Gauteng has a greater awareness around e-waste recycling (Cape E-waste, interview, 2017), which is ironic since the Western Cape is considered the 'greener' province.

However, this 'green' reputation may be lived up to through the Atlantis Special Economic Zone (SEZ) in the Western Cape. The Atlantis SEZ is proposed to serve as a regional e-waste processing hub. Its appeal includes low-cost industrially-zoned land available for lease to companies using 'green technology' as part of the national Department of Trade and Industry's (DTI) project (GreenCape, 2018). This presents a great opportunity for prospective recyclers looking for premises, and existing recyclers who are planning to up-scale or relocate their premises. However, the location of the site is 60 km from Cape Town CBD and suburbs, where most of the major clients in the Cape Town area are situated. This not only presents transport cost implications but also travelling time. Although the Atlantis SEZ may not work for a small-to-medium scale collection and dismantling operation, it may be a prime location for a large consolidation plant for end-processing.

Most recyclers believe that Gauteng will remain the largest e-waste hub in the country which may lead to an increase in competition and a decrease in availability of the already limited e-waste volumes. Some recyclers are responding to this by finding alternative sources of e-waste in other provinces and neighbouring countries. Furthermore, recyclers in the Western Cape and Kwa-Zulu Natal are acting as collection agents and channelling their volumes to larger, more established recyclers such as Cape E-waste and Indalo Resources Ltd, who then pass their volumes on to Desco and the like. This ultimately promotes the idea of centralised processing plants, thereby further solidifying e-waste hubs in certain areas.

Additionally, recyclers are expanding and diversifying their operations to include other metal-containing waste streams such as mine and automotive wastes (Lydall, Nyanjowa & James, 2017). This is similar to large e-waste processors in European countries who perform metal extraction processing from a wide array of industrial metal-containing wastes. These companies include Umicore in Belgium and Boliden in Sweden.

Another factor informing the location of e-waste recyclers is their access to e-waste volumes. Different types of e-waste generators have access to different levels of recyclers, and vice versa. Small-to-medium recyclers may only have access to small businesses and households, whereas larger recyclers have access to government and industry e-waste tenders. This is illustrated in the e-waste collection network described in Section 5.2.1.

5.1.3.2 E-waste Sources

The main sources of e-waste collected in SA include government departments (contributing 45% of total collected volumes), private businesses (35%) and households (20%), according to the study by Lydall, Nyanjowa & James (2017). These results provide a good overview of the relative sources of the total volume handled by the 27 e-waste recyclers that partook in the study. However, this breakdown is mainly representative of larger recyclers given their large throughputs compared to smaller recyclers.

Government procurement policy requires replacing ICT and consumer electronics every five years, which has increased potential access to high-value electronics for those in the e-waste value chain. These volumes will hopefully be made accessible through Operation Phakisa's government-wide e-waste asset management system, as discussed in Section 5.1.2. However, this may only be accessible to larger recyclers as is currently the case (Lydall, Nyanjowa & James, 2017).

Private businesses and institutions are the main supplier of e-waste to small-to-medium recyclers (Lydall, Nyanjowa & James, 2017; Cape E-waste, interview, 2017). Businesses usually seek out e-waste recyclers due to legal obligation for appropriate disposal. Furthermore, businesses are sometimes motivated to recycle their e-waste through incentives such as recycling rebates. Companies such as GreenOffice, a printing equipment recycler, provide such rebates (Environmental Risk Officer, interview, 2017).

However, it is understood that businesses may also store large volumes of e-waste due to data security risks (Desco, site visit, 2017). Data destruction is thus an additional service provided by e-waste recyclers.

E-waste from households is mainly accessed through informal waste pickers, waste drop-off sites with sorting facilities, retailer take-back schemes, and drop-offs to recyclers directly from household consumers. Retail drop-off sites include Pick 'n Pay, Woolworths and Builder's Warehouse, or take-back schemes such as that operated by Vodafone. Desco also has a waste drop-off initiative in partnership with Samsung, Makro, and Incredible Connection stores (Desco, site visit, 2017). However, e-waste from households may enter the value chain through interventions resulting from the IndWMP as well as the prohibition of e-waste to landfills in 2021, as previously mentioned.

The study by Lydall, Nyanjowa & James (2017) further concludes that the largest e-waste category recycled is information and communication equipment, and consumer electronics (79%), followed by large and small household equipment (15%) and lighting equipment (4%). These results not only give insight into the relative volumes of the types of e-waste generated but also that which has been intercepted by recyclers. The e-waste sub-groups that forms of the 'other' 2% are most likely electric and electronic tools, and security and health care equipment. However, it should be noted that the relative volumes of each type of e-waste do not directly correlate to the relative number of units of devices recycled.

Furthermore, based on these results, insights into the products and revenues that may be expected can be determined from each e-waste category. For example, the main outputs from information and communication equipment, as well as consumer electronics, are PCBs and central processing units (CPUs), which are important sources of precious or high-value metals. Whereas, small and large household equipment is a major source of ferrous and non-ferrous metals for scrap metal markets (Lydall, Nyanjowa & James, 2017; Cape E-waste, interview 2017; NC Electronix, interview 2017, Desco, site visit, 2017).

5.2 The E-waste Value Chain & Stakeholders

The e-waste value chain in SA comprises of four main stages, namely (i) collection and storage, (ii) dismantling and sorting, (iii) pre-processing, and (iv) end-processing. Additional stages in the value chain include generation, refurbishment, and re-use, as well as residue disposal. The value chain stages are depicted in Figure 5 in Section 2.2.

5.2.1 Stakeholder Mapping

Both direct and indirect stakeholders are involved in the execution of value chain activities. The direct stakeholders usually perform one or more of these activities such as collection and recycling. While indirect stakeholders either inform the value chain through policy-making or form part of the electronics industry before these products become waste.

5.2.1.1 Direct Stakeholders

The direct stakeholders include generators, collectors, dismantlers and processors of e-waste. These stakeholders are listed in Table 17; the shaded cells containing an 'x' indicates that value chain activity that each stakeholder performs.

E-waste generators such as households, businesses and institutions, generally only consolidate and store e-waste until it is collected. Buy-back centres and e-waste drop-off facilities consolidate, store and also distribute e-waste fractions or whole devices to recyclers. Distribution is also conducted by waste management contractors or large, integrated waste management collection companies. They are usually employed by municipalities to collect waste intended for landfill disposal.

Refurbishment is executed by small retail repair stores, as well as larger specialised companies such as Just PCs in the Western Cape. Just PCs originally performed dismantling, however, they have stopped and now specialise in refurbishment. They contract recyclers to take process those items that are beyond repair (NC Electronix, interview, 2017). Refurbishment is a generator of e-waste in the form of broken components and unused parts, making it a complementary activity to e-waste recycling.

Larger recyclers such as Desco also has a refurbishing business sector on-site (Desco, site visit, 2017). Many small-to-medium e-waste recyclers also provide refurbishment as a service, some of which claim that refurbishment makes up 60% of their revenue while recycling only accounts for the other 40% (Lydall, Nyanjowa & James, 2017). Cape E-waste (interview, 2017) mentions that small e-waste recyclers cannot exist without refurbishing, as it brings in most of their revenue. About 15-20% of their e-waste volumes are refurbished which are mostly ICT and consumer electronics.

Table 17: Direct Stakeholder Activity Map (adapted from Lydall, Nyanjowa & James, 2017)

	Consolidation & storage	Collection & transport	Refurbishing	Dismantling & sorting	Pre-processing	End-processing	Value fraction distribution (Local)	Value fraction distribution (International)
Households	x							
Private sector: Businesses & institutions	x							
Public sector: Businesses & institutions	x							
Buy-back centres & drop-off facilities (including retailers)	x						x	
Waste management contractors		x						
Refurbishers		x	x				x	
Waste pickers		x		x			x	
Small-to-medium recyclers	x	x	x	x			x	x (plastics)
Large recyclers	x	x	x	x	x		x	x (PCBs, plastics, ferrous & non-ferrous metals)
End-use recyclers / Refineries						x	x	x (precious metals)

There is thus a financial incentive to encourage more e-waste recyclers to incorporate refurbishment activities into their business. Refurbishment requires skilled labour, however – two interviewees report that they have acquired their skill and experience through apprenticeships from their peers or learning on the job (NC Electronix, interview, 2017; Smileys Electronics, interview, 2017).

Informal, individual subsistence recyclers, or waste pickers who handle negligible daily volumes of e-waste, usually collect and dismantle e-waste to sell on to established recyclers or buy-back centres. Their main motivation is to support the livelihoods of their families. Waste pickers play a key role in accessing waste that would otherwise end up in municipal landfills or dumpsites, as mentioned in Section 4.1.2. Other characteristics of their operations include little to no technology investment, an unregulated environment and fluctuating workload. Furthermore, the financial or job security for waste pickers is highly uncertain due to inconsistent e-waste flows throughout the year (NC Electronix, interview, 2017).

Small recyclers handle volumes of up to 100 tons per year, while medium recyclers handle volumes between 100-1000 tons of e-waste per year. See Table 16 in Section 5.1.3.1 for further illustration of annual volumes handled by various e-waste recyclers in 2015. Small-to-medium recyclers conduct activities in the initial stages of the value chain including collection and storage, as well as dismantling and sorting. These recyclers are registered service providers; however, they have not obtained full legal compliance.

Larger recyclers and distributers usually conduct pre-processing as well as initial value chain activities. There are high barriers to entry at the pre-processing and processing stages due to limited access to sufficient e-waste volumes to make it worthwhile. Therefore, larger recyclers tend to operate as consolidators of e-waste as they receive volumes collected by smaller recyclers and waste pickers who act as collection agents for them. They also tend to focus on bulk tenders from private companies and government departments across a wider geographical footprint.

Furthermore, they act as distributors of e-waste value fractions after the pre-processing stage, by selling them on to end-processors both locally and internationally through export. End-processors comprises of local refineries such as SA Precious Metals and

Gauteng Refinery, and international large-scale smelting operations such as Umicore and Boliden. They extract and refine metals from e-waste fractions and trade metals products.

Local processing of e-waste does occur; however, the majority of e-waste volumes have only undergone dismantling and pre-processing stages before they are exported. This reveals that SA largely operates in alignment with the Bo2W philosophy, as discussed in Section 2.4.1. However, strides towards local processing have been made. Whether this is economically feasible and practical given the limited volumes collected, is the key question regarding the future of SA's e-waste economy.

5.2.1.2 Indirect Stakeholders

The stakeholders who inform or influence value chain activities indirectly are government structures involved in policymaking and industry development, voluntary e-waste management structure, as well as the parties involved in the EEE industry involved in the IndWMPs.

Voluntary industry networks play an important role in providing e-waste collectors and recyclers with access to information regarding policy updates, best practices, as well as access to a national and international e-waste network. Being a member of these networks also provides credibility in terms of legal compliance and proficient service provision. Some clients request membership certificates before going into business with e-waste recyclers (NC Electronix, interview, 2017).

However, both networks allow for members at different stages of legal compliance to join. The SAEWA used to only accept members who are fully legally compliant but were accused of not being inclusive (Karcher, interview, 2017). The SAEWA responded to this by implementing a tiered system, outlining specific qualifications of members for each tier. Each tier makes a distinction between legally compliant collectors and recyclers, those on the path to becoming legally compliant, advisory members, as well as interested parties such as researchers. For those companies who are not yet legally compliant, they are placed in an affiliate program which provides mentorship and support.

On the other hand, eWASA does not differentiate between compliant or non-compliant members. They have established before SAEWA and thus has a bigger membership. The credibility of belonging to these networks, eWASA in particular, has been challenged by Lawhon (2012). There is a misconception that eWASA members are fully legally compliant, however, this is not the case. One recycler believes that e-waste networks should be stricter in its selection criteria to prevent non-compliant and illegal recyclers from gaining clients (NC Electronix, interview, 2017).

These industry bodies can provide a level of governance and enforcement of legal compliance. SAEWA already does this through membership selection criteria and support for non-compliant members. SAEWA is also developing norms and standards for their members to comply with. Furthermore, they provide access to and liaison with government bodies (Cape E-waste, interview, 2017).

Other initiatives such as the Recycling Action Group (RAG), Metals Recycling Association of SA (MRA), National Recycling Forum (NRF), and Western Cape Industrial Symbiosis (WISP) also contribute to knowledge sharing, network development and general industry management. More about these initiatives and roles can be found in Table 22 in Appendix D.

5.2.2 E-waste Collection & Value Fraction Distribution Networks

The e-waste collection and value fraction distribution network will be discussed in this section, including imports and exports.

5.2.2.1 The E-waste Collection Network

The e-waste collection network has already been alluded to in previous sections. E-waste collection is performed by multiple stakeholders both informally and formally, at varying scales. Collection sources and channels are diverse and interconnected as illustrated in Figure 20.

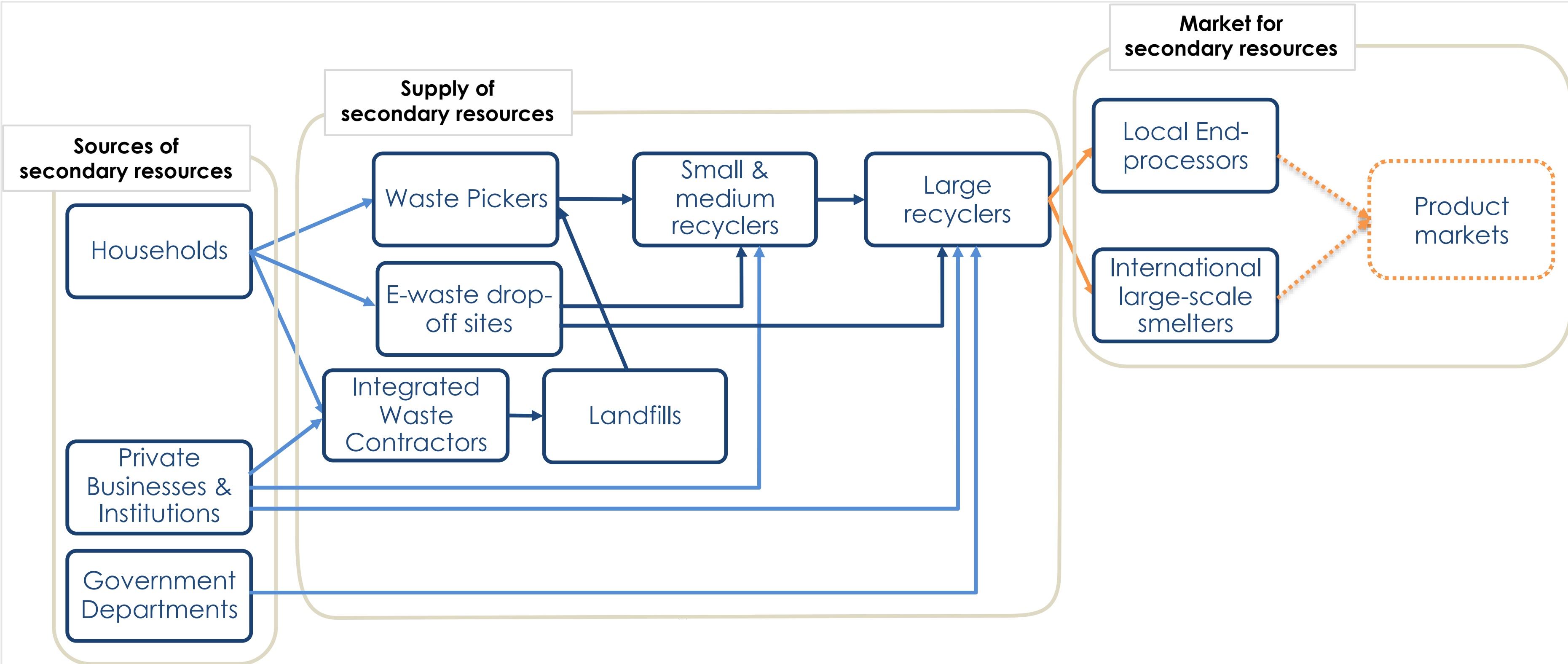

Figure 20: The E-waste Collection Network

E-waste collection is either done at source or via aggregation sites such as designated e-waste drop-off sites and retail take-back initiatives. Unfortunately, most e-waste is not separated from general waste at source and thus end up in municipal collection systems. The mixed waste streams are transported to municipal landfill sites where sorting and separation do not formally occur.

However, waste pickers sort through household or business waste, as well as waste at landfill sites. They then sell their collected volumes as whole devices or as dismantled fractions to small and medium recyclers (Bondolfi, 2007).

Small and medium recyclers receive additional e-waste volumes from private businesses. Once dismantled, they sell their fractions to large recyclers. Some of the larger recyclers only accept value fractions and reject the non-viable fractions. This proves that profitability is the main agenda for these companies.

Desco goes as far as training individual, informal collection agents how to dismantle items to separate the valuable fractions from the less valuable peripherals (Desco, site visit, 2017; Karcher, interview, 2017). They offer a higher price for the value fractions and will not buy the rest. This culture is known as 'cherry-picking' which is common in the waste sector. This leaves informal collectors with no choice but to dump the non-valuable components.

Large, integrated waste management companies also collect e-waste among other wastes, dealing mainly with large businesses and institutions with an extensive logistics network. These include companies such as Waste Plan, Pikitup and SmartMatta (Lydall, Nyanjowa & James, 2017). Some of these companies have sorting facilities and organise e-waste to be recycled. This is a good example of utilising existing infrastructure, particularly for transport and logistics. However, the challenge is often that waste is contaminated to such a large degree that separation and sorting are not possible. Companies specifically focused on e-waste also collect directly from the source or via designated e-waste drop-off sites.

Overall, the large recyclers act as an e-waste aggregator and distributor of bulk e-waste volumes. Whereas, the waste pickers and small-to-medium recyclers as collection agents and dismantlers, dealing with much smaller volumes. Each type of recycler brings a different collection strategy, thus diversifying the range of sources as well as the reach of the network.

Large recyclers are the main distribution channel of e-waste value fractions to end-processors, both locally and internationally. This will be discussed further in the next section.

5.2.2.2 E-waste Value Fractions and Exports

The main e-waste value fractions include metal scrap, metal-rich fractions such as PCBs and batteries, uncontaminated glass and plastics, these are listed in Table 18. The destination of each value fraction stream is also listed. Export flows are further illustrated in Figure 21.

Table 18: List of e-waste value fractions and where it is mainly found (Bondolfi, 2007; Lydall, Nyanjowa & James, 2017)

Value fraction	Main e-waste component	Destination
PCBs (graded according to precious metal content)	Major computing/ electronic component of devices	Mostly exported for further processing; some processed locally
Steel	Device & component casing	Mainly processed locally; some exported for further processing
Aluminium	Device & component casing	Exported
Copper (excluding that found in PCBs)	Electrical wiring, hard disks	Exported, processed locally
Glass	CRT and LCD screens	Stockpiled, landfilled or locally processed
Plastics	Device & component casing, electrical wiring	Some fractions recycled locally, landfilled, stockpiled or exported
Phosphor Powders (containing Rare earth elements (REEs)	Fluorescent lighting tubes	Stockpiled, or exported
Batteries (nickel-cadmium; lithium ion)	Energy storage units in portable devices	Stockpiled, landfilled or exported

Exports of various fractions occur from the major e-waste hubs, namely, Western Cape, Eastern Cape, Gauteng and KwaZulu-Natal as illustrated by the dark blue arrows in Figure 21. Exporting 'raw' e-waste for recycling outside of SA is not very common without some initial processing or value-adding stage.

PCBs of different grades are pre-processed via size reduction before being shipped and sold to European and Asian markets for further metal extraction processing and refining (Lydall, Nyanjowa & James, 2017). PCBs are priced by the importing company using internal assay methods to determine precious metal content (International precious metals refinery, informal discussion, 2017). Pricing negotiations are therefore out of the control of SA recyclers. Upon interviewing SA recyclers who export PCBs, details of the exporting deals were withheld, such as the names of the importing companies, trade volumes, as well as pricing estimates. This highlights the competitive nature of the industry. Desco reluctantly confirmed its trade with Boliden, a large-scale smelting operation in Sweden (Desco, site visit, 2017).

PCBs, phosphor powders, and batteries are exported to Europe via Eastern Cape or Kwa-Zulu Natal ports. 90% of PCBs leave via Gauteng and Kwa-Zulu Natal, while only 10% leaves via Eastern Cape. This is a reflection of the respective market distribution in terms of e-waste volumes handled in 2015 for each of these provinces as previously discussed. This also indicates that most PCBs from the Western Cape gets transported to Gauteng.

Rare Earth Elements (REEs) are another value component found in phosphor powders. These powders make up 3 wt.% of fluorescent lamps, however, REE volumes are small given the low concentrations in phosphor powders. REE product markets include permanent magnets, nickel metal hydride batteries and lighting equipment (Binnemans & Jones, 2014). Approximately 60% of phosphor powders from lighting equipment was exported in 2015, while the rest stockpiled by E-Waste Africa and Reclite (Lydall, Nyanjowa & James, 2017). Reclite is currently investing in research into REE extraction and markets (Reclite, site visit, 2017). This may present a potential economic opportunity for lighting recyclers in SA.

Ferrous and non-ferrous metals are mostly exported to Europe and Asia mainly from Gauteng and Kwa-Zulu Natal (Lydall, Nyanjowa & James, 2017). However, SA has a large local scrap metal market with end-processing and manufacturing operations for steel and copper. One such vertically integrated processor is the SA Metals Group.

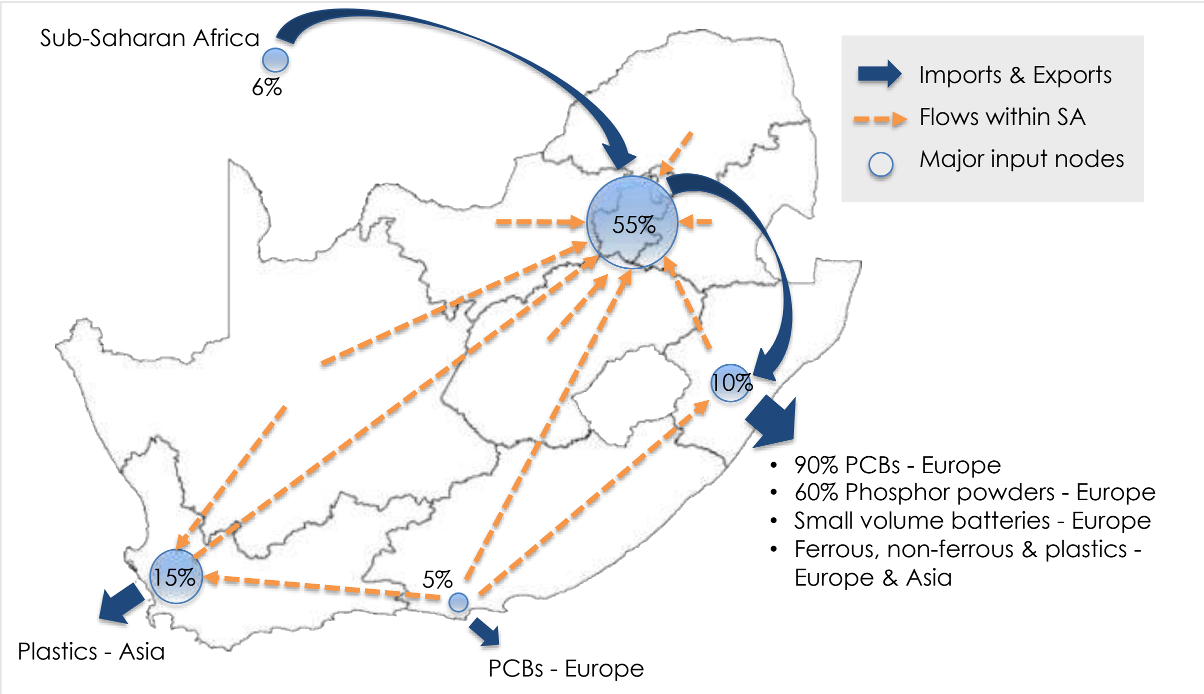

Figure 21: E-waste import, export and local volume flows in South Africa (adapted from Lydall, Nyanjowa and James, 2017)

Furthermore, interventions to support local end-processing markets for ferrous and non-ferrous metals is done through the International Trade Administration Commission of South Africa (ITAC). Scrap metal dealers are required to apply for an international trade permit, however, before this is granted the product available for trade is circulated to the database of local buyers. Preference would then be given to any local buyer who can buy the product for 30% less than the export sale (SA Metals Group, site visit, 2017). This intervention is not always in the best interests for local sellers in terms of profitability, however, it supports local buyers and processors. This type of local processing incentive is a possible strategy to be used for the e-waste industry once local end-processing has been established.

Plastics are exported to both Europe and Asia. Most recyclable plastics from e-waste used to be exported to China for recycling, however, recent Chinese legislation bans plastic and other solid waste imports as mentioned in Section 4.1.2. Therefore, e-waste recyclers either stockpile plastics in the meantime as other markets are being pursued or dispose of them in municipal landfills (Cape E-waste, interview, 2017; Karcher, interview, 2017b).

Recyclers are now forced to find alternatives to the Chinese market. Cape E-waste shared that they found a potential international client willing to buy certain plastics. However, they were not willing to disclose the details of the company or country until a time the deal was settled (Cape E-waste, interview, 2017). This further alludes to the competitive and sensitive nature of the industry, as well as the unpredictable nature of the market forces, which encourages companies to think on their feet and adapt to the ever-changing environment. Moreover, this illustrates the international linkages and interconnectedness of different global forces. In order for a country to gain stability, it should be able to rely solely on local infrastructure and markets.

Some e-waste fractions containing hazardous elements, such as CRT monitors, plastics containing BFRs, and batteries are still sent to hazardous landfills due to the lack of recycling technology for these fractions (Finlay, 2005). These are thus labelled non-viable fractions.

Legislation for diverting and prohibiting e-waste from general waste landfills in SA will come into effect in the next few years (Dittke, interview, 2018), as discussed in Section 4.2.4. Recyclers will thus be forced to dispose of the non-viable fractions in official hazardous waste landfills. This comes with a hefty fee, which is often too expensive for smaller recyclers (Karcher interview, 2017; NC Electronix, interview, 2017). Furthermore, it is unclear whether these disposal techniques, such as cement encapsulation, are suitable and effective for these fractions. Most recyclers end up stockpiling or illegally dumping these fractions to avoid steep disposal costs. Negative environmental and health impacts are anticipated due to poor storage conditions, and unregulated dumpsites (Bondolfi, 2007).

Other hazardous fractions include those containing radioactive materials which require a particular procedure for its handling. Any radioactive sources should be listed with the Directorate of Radiation Control and the Nuclear energy corporation of SA (NECSA). Furthermore, disposal or handling of this waste should be reported to these bodies. Radioactive sources could be found in medical equipment such as X-ray machines, manufacturing equipment, and even smoke detectors (Environmental Risk Officer, interview, 2017; SA Metals Group, site visit, 2017). These sources can end up with e-waste recyclers from time to time without their knowledge if they are not managed properly. Some recyclers are not even aware of them (NC Electronix, interview, 2017; SA Metals Group, site visit, 2017), which poses a great threat to manual dismantlers who will inevitably come into contact with such materials. NC Electronix (interview, 2017) mentioned that information regarding radioactive sources has never been communicated to them and should be the duty of the relevant government body.

5.2.3 Technologies used for E-waste Processing

E-waste processing technologies have been discussed in the literature review, Section 2.3. Furthermore, a detailed overview of technologies used for e-waste processing in SA is outlined in Lydall, Nyanjowa & James (2017). The following section will discuss which end-processing technologies work for the SA context.

5.2.3.1 Large-scale Metal Extraction Technologies

Large-scale secondary metal processors utilise integrated smelting and refining technologies to process mixed streams, including e-waste. These smelting houses are located in countries in Europe, North America and Asia. Most of these smelters were existing infrastructure previously used for primary copper mineral ores and modified to process these industrial and post-consumer waste streams. Examples of these modified smelting operations are Boliden in Sweden and Umicore in Belgium.

A major advantage of these large-scale operations is that they are highly regulated in terms of environmental and occupational health and safety legislation. Furthermore, co-processing e-waste with other metal-containing waste streams may account for economies of scale necessary for these operations. However, this is accompanied by high operating and regulatory costs, dependence on large volumes of feed, and is highly reliant on technology with limited labour requirements (Schluep et al., 2009).

Businesses in SA have investigated the use of smelting technology for metal extraction from unmixed waste PCB streams. According to Lydall, Nyanjowa & James (2017), Rand Refinery and Mintek, in two separate projects, have attempted metal extraction and refining from waste PCBs streams using pyrometallurgical technologies. However, processing discontinued for both projects due to toxic off-gas emissions, as well as insufficient volumes of PCBs available for the economies of scale necessary.

Furthermore, Gauteng Refinery and Anglo Platinum indicated that the business case for metal extraction from PCB streams is not competitive. Reasons include too low precious metal concentrations compared to mineral ore concentrate, excessive initial capital costs for modifications to existing equipment, as well as issues concerning feedstock analysis (Lydall, Nyanjowa & James, 2017). However, Gauteng Refinery is believed to produce and trade metals from e-waste. A jeweller in the Western Cape claims to produce all their jewellery pieces from reclaimed metals from e-waste bought from Gauteng Refinery (informal discussion, 2018).

A possibility to improve the economies of scale and to diversify the feed streams could be to introduce other secondary metal streams. This is the case for existing and successful large-scale European smelters. These can include industrial wastes and by-products, precious metals sweeps and bullions, spent industrial catalysts, car exhaust catalysts and other e-waste components (Hageluken, 2006). This approach is yet to be investigated for an existing SA smelter. Large investments in equipment modification for effluent treatment is anticipated (Mintek, site visit, 2017). However, the economics, legal frameworks and technical feasibility of this route should be further investigated.

5.2.3.2 Alternatives to Large-Scale Smelting Operations

A prospective technology for small-to-medium scale operation, as is necessary for SA due to the low volumes of waste PCBs available, is selective and sequential leaching of metals via a purely hydrometallurgical route. The benefits of using hydrometallurgy instead of high-temperature processes are multiple. This includes increased recovery, increased selectivity of extraction, lower energy requirements, and lower negative environmental impacts caused by waste products, particularly gas emissions (Cui & Zhang, 2008; Tuncuk et al., 2012; Akcil et al., 2015).

A number of variations of hydrometallurgical processes are widely covered in literature (Kamberović et al., 2009; Tuncuk et al., 2012; Akcil et al., 2015; Anderson & Cui, 2016; Birloaga, Michelis & Vegliò, 2016), however, economic projections, feasibility of the scale of operation, and technical demonstration through pilot-scale projects need to be investigated further.

One such pilot project has been investigated by SA Precious Metals, primarily a gold refining company. SA Precious Metals developed a hydrometallurgical process for 100% metal extraction from waste PCBs. Chinese technology is used to shred the PCBs before processing to liberate the metals. The throughput capacity of the plant is two tons per day, with the prospect to scale-up to four tons per day. As the process is modular, it can be established close to collection or pre-processing hubs (Lydall, Nyanjowa & James, 2017; Mintek, site visit, 2017).

Furthermore, SA Precious Metals are very selective on feed composition with a preference towards high-grade PCBs. However, a mixture of different grades may be used to achieve a high-grade average feed composition (Mintek, site visit, 2017). This indicates that the process may be sensitive to feed composition. Further details of this technology have not been publicly reported to date, due to its proprietary nature. There is no indication as to whether this process will reach the commercial manufacturing stage, again due to limited volumes available, especially high-grade PCBs.

Another hydrometallurgical pilot project, HydroWEEE (2009-2012) and the HydroWEEE demo (2012–16) funded by the European Commission, reported to recover precious and rare earth metals at a purity above 95%, from LCDs, fluorescent lamps, CRTs, batteries, and PCBs. The products can then be sold for use in electroplating and other end-use applications. The academic research behind the process stems from Kamberović et al. (2009), Birloaga et al. (2013) and Birloaga, Michelis & Vegliò (2016). The mobile and modular plant is intended to be used as a service to SME's in order to bypass larger recyclers, distributers and end-processors. Furthermore, it can relieve the transport costs associated with stationary and centralised plants by moving to different recycling hubs to service multiple SME's.

The key features of the process are its modular and mobile design fitting into two shipping containers, and it can handle a variety of waste streams through batch treatment. However, it accepts 400 kg of metal-rich, powdered feedstock (approximately 1mm particle size) per batch. This requires pre-treatment of material such as dismantling, shredding, milling, pulverisation, and initial physical separation techniques, which may require high energy inputs. Pre-treatment may not be accessible for SME's due to the necessary technology investment, hence there is an intention to incorporate mobile pre-treatment plants with this technology (European Commission, 2014b).

It should be noted that two separate process flow sheets are used to process precious metal-rich wastes such as waste PCBs, and rare earth metal-rich wastes including LCDs, fluorescent lamps, CRTs, and Li-ion batteries (Beolchini et al., 2013).

Small-scale, informal processing of waste PCBs for copper and gold extraction have also been known to exist in SA. Details of these operations are not documented or seen, however, the numerous reports from e-waste recyclers cannot be ignored. These include two reported backyard operations to extract gold and copper from PCBs in the Western Cape. Some electronic repair stores sell their PCBs to them due to the higher prices they receive compared to those offered by Square Mobile (interview, 2017). Another informal operation was reported in Gauteng, where palladium was being extracted from telecommunication cables using harmful chemicals. Exposure to these chemicals caused long-term, negative health effects on the workers on-site (Cape E-waste, interview, 2017).

E-waste recyclers report to have learnt how to use readily available chemicals to extract metals seen on YouTube videos (NC Electronix, interview, 2017). These can be found on the following YouTube channels: *sreetips; Precious Metal Recovery; gold recovery;* and *Michael Ciccarello*. These channels are public and have hundreds and up to thousands of subscribers confirming their wide distribution. Informal operations typically employ aqua regia leaching of manually separated gold contacts and acid leaching of PCBs (nitric acid/sulphuric acid) to extract gold and copper, respectively (Goosey & Kellner, 2002). Uncontrolled disposal of wastewater and emissions from such processes incur serious environmental and occupational health risks if no precautions are taken.

These backyard operations usually operate under the radar precisely because they do not comply with environmental and occupational health legislation. Two recyclers in the Western Cape admit that they do not aspire to conduct any chemical processing as part of their operation. They do not have the expertise or permissions to start such a process and are aware of the potential risks associated with it, although, they are supportive of local end-processing (NC Electronix, interview, 2017; Cape E-waste, interview, 2017).

5.2.3.3 Plastics Recycling

Plastics from e-waste could be a potential opportunity for SA in terms of separation and recycling. One of the main challenges for plastics recycling is the difficulty of separating plastic materials, as they are mostly unlabelled and often composed of mixed grades. Consequently, plastic recyclers in SA will not accept these fractions (Cape E-waste, interview, 2017). Furthermore, most of the plastics in e-waste contain BFRs which results in toxic emissions when treated using thermal recycling technologies (Mahesh et al., 2016). Technological research should thus focus on plastics separation techniques, solutions for mixed-grade plastics, as well as treatment of plastics containing BFRs.

The recent ban of imports of recyclable waste to China and global restrictions on waste trade encourages local processing. Technologies such as extrusion and pelletising for the remanufacture of plastic products as well as novel applications such as filament for 3D printing is currently available. However, factors such as quality of plastics, presence of BFRs, potential local and international markets for 3D printing filament, should be considered.

Mintek in collaboration with Desco, Plastics SA and Use-It, is conducting a pilot project for pelletizing plastics from e-waste. These are mainly type-7 or ABS plastics (Mintek, site visit, 2017). They are looking into offering a service to SMEs to process their plastics for a fee. This allows for small businesses to concentrate on supply and preparation of plastics for processing, as opposed to the processing itself.

5.2.4 E-waste in Research

DST together with the CSIR have recently invested in and endorsed several Waste RDI Roadmap projects for the development of technological solutions for priority waste streams, including e-waste. They specifically promote economic and job creation opportunities as well as SME development. Key features of these initiatives include e-waste dialogue workshops with industry and research institutions, research funding as well as small-to-medium enterprise development programmes (DST, 2014). These initiatives are key in creating a collaborative network between government departments, industry and research institutions. However, it is uncertain whether, and to what extent the DEA is involved in the Roadmap. As managers of the legal framework governing the waste industry, their input is key in providing an enabling legal environment for technology and SME development. Therefore, the DEA involvement in the Roadmap should have suitable priority and visibility.

Research institutions, including the University of Cape Town and Stellenbosch University, are currently investigating hydrometallurgical and bio-hydrometallurgical processes for metal extraction from waste PCBs. These local research initiatives offer the necessary contextual insight for existing technical solutions to succeed, but there is no immediate pathway to implementation of such technologies.

Bob et al., (2017) proposes a model that draws on resources at research institutions such as the Vaal University of Technology to set up a demonstration centre to develop and test new technologies for e-waste processing. Furthermore, the proposal calls upon training institutions to organise upskilling and training workshops for local communities and entrepreneurs.

The UCT Urban Mining team had a similar vision to provide demonstration, training and technical expertise for SMEs in the field. The team is comprised of engineers, economists, and lawyers. The interdisciplinary research concept envisaged a containerised concept for small-scale processing of e-waste in local communities in SA. This included the investigation into socio-economic factors, legislation and policy as well as process development to specifically suit the SA context. This research is continuing under the Minerals to Metals Initiative and the HydroMet research group at UCT.

As previously mentioned, Mintek had also researched pyrometallurgical processing of waste PCBs, e-waste plastics processing, as well as the study of the technological landscape of the e-waste industry in SA.

Local academic and industrial research is integral to local industry development. Researchers provide reliable proof of concept research and may offer training and technical expertise for scaling and distribution of technologies. However, it is important that knowledge is shared and utilised in the local context, as this is one of the guiding principles in CE design. Furthermore, academic research institutions provide the added benefit of having the necessary facilities and legal permissions to conduct testing of processing technologies. Karcher (interview, 2017) adds that government bodies are more likely to grant legal permissions for pilot projects through academic or research institutions as opposed to SMEs due to health, safety and environmental risks.

5.2.5 The Economics of E-waste Recycling

The economics of the local e-waste value chain is important in understanding the prospects for industry development, especially when considering developing a local end-processing sector. Factors affecting recyclers include cash flow issues, fluctuating feedstock and fluctuating product prices.

The potential for recovering economic value from e-waste remains as the main driving force in the e-waste recycling industry. The variety of products and volumes that can be recovered also adds to the business case. However, the collection of these products, integrated recovery technologies to recover all these elements at a feasible cost, as well as costs of dealing with non-viable or hazardous fractions, are the main limitations.

The United Nations University (UNU) estimates the raw material value of the 44.7 million tons of e-waste generated in 2016 was ZAR 881.6 billion (€ 54.8 billion) (Baldé et al., 2017). The breakdown of raw materials and value potential is listed in Table 19. Copper, gold and plastics account for 17.4%, 34.4% and 27.4% respectively of the total value.

The metal prices were based on EU markets and would thus differ internationally. The methodology used to estimate the economic value has not been explained. It is therefore unclear whether the cost of recycling, including collection, dismantling and recovery, has been taken into account.

Table 19: Potential economic value of raw materials found in e-waste for 2016 (adapted from Baldé et al., 2017)

Material	Kilotons	Million ZAR (% of total value)
Fe	16 283	57 598 (6.5%)
Cu	2 164	153 143 (17.4%)
Al	2 472	57 646 (6.5%)
Ag	1.6	14 214 (1.6%)
Au	0.5	302 942 (34.4%)
Pd	0.2	54 173 (6.1%)
Plastics	12 230	241 887 (27.4%)
	TOTAL	**881 603**

The cost of recycling includes operating costs incurred from the very beginning of the value chain such as transport, rent of premises and/or equipment, labour for dismantling and separation processes, and energy and resource costs for final recovery steps. An additional cost that is not always accounted for are the cost of disposal for the non-viable (or negative value) fractions.

Most small recyclers in SA provide a free collection service for small volumes of e-waste as they require feedstock for their recycling activities. Furthermore, it is very common for e-waste recyclers to buy e-waste from generators. This can be done directly or via a recycling rebate; GreenOffice, a printing equipment recycler, is an example of an e-waste recycler offering rebates. However, transport costs remain the highest expense for many small to medium recyclers due to their necessarily large collection radius (NC Electronix, interview, 2017; Cape E-waste, interview, 2017). On the other hand, larger generators such as Telkom would pay for the recycling service and would offer tenders or long-term contracts to e-waste recyclers.

Another notable expense for small to medium e-waste recyclers is operating costs including rent and labour, as well as the cost of legal compliance. This will be outlined in more detail in Section 5.3.2.

Technology for size reduction activities and advanced separation technologies, used in pre-processing stages, require large capital investments. Shredders used by Desco are bought from Germany and China cost R3 million and R1,5 million, respectively. A local second-hand shredder may cost approximately R250 000. Lamp recycling equipment used by Africa E-waste and Reclite costs between R1,5–10 million (Lydall, Nyanjowa & James, 2017). These capital investments are largely unaffordable to smaller companies. Furthermore, it is only beneficial if product markets for the processed materials are accessible. SA's e-waste recycling industry thus remains small-scale in operation and capacity compared to industrial European recyclers. Economies of scale is a key factor when considering processing activities and technologies.

Cash flow is another major factor for smaller recyclers. A small, entrepreneur in the Western Cape, Square Mobile, looked into working with SA Precious Metals Ltd to process a batch of mobile phone PCBs to extract gold and other metals using their hydrometallurgical process (Square Mobile, interview, 2017). Several challenges arose for them, including:

- Accumulating and storing 10 tons of PCBs as the minimum volume they would process;
- Paying for the batch to be shipped from the Western Cape to Gauteng;
- Negotiating a split profit of 40/60; and
- Waiting for the split of profits to be paid only three months later.

For international trade, additional issues arise. E-waste recyclers in SA have no control over the pricing of PCB batches exported to Europe. These batches are priced only once they get to the processing facility where they are assayed. It should be noted that the going prices for e-waste exports were not disclosed at any level; probably to maintain competitive advantages.

Further issues include:

- The company that is pricing the batch is the one doing the assaying which raises a conflict of interest;
- The SA recycler only gets notified of this price once the batch has already been delivered to the European processor;
- Transport costs and export levies are thus paid before the batch is paid for, which is most likely at the cost of the SA recycler.

Further insights into how e-waste is governed in SA will be discussed in the following section, with specific reference to requirements for its handling, reporting and licensing.

5.3 How E-waste is Governed in South Africa

E-waste primarily forms part of the broader category of hazardous waste, along with batteries, and chemical waste. This is consistent across national, provincial and municipal legislation. There is not much differentiation in legislation between the different types of hazardous wastes, except practical differences such as the regulations regarding the transporting of liquid chemical waste compared to that of transporting e-waste (Dittke, interview, 2018).

The main pieces of legislation that may impact the e-waste recycling industry is as follows (DEA, 2016c):

- The South African Constitution (Act 108 of 1996)
- Hazardous Substances Act (Act 5 of 1973)
- Health Act (Act 63 of 1977)
- Environment Conservation Act (Act 73 of 1989)
- Occupational Health and Safety Act (Act 85 of 1993)
- National Water Act (Act 36 of 1998)
- The National Environmental Management Act (Act 107 of 1998)
- Municipal Structures Act (Act 117 of 1998)
- Municipal Systems Act (Act 32 of 2000)
- Mineral and Petroleum Resources Development Act (Act 28 of 2002)
- Air Quality Act (Act 39 of 2004)
- National Environmental Management: Waste Act, 2008 (Act 59 of 2008)
- National Environmental Management: Waste Amendment Act, 2014 (Act 26 of 2014)

Each of these laws approaches e-waste from varying perspectives and while it provides a comprehensive framework, it also creates a sense of uncertainty and potential overregulation. Furthermore, these laws are set by different government departments and are implemented at various levels of government – national, provincial or municipal – each with different approaches to e-waste management. This means that one would need to consult a vast collection of legislation to understand the legal requirements of e-waste handling of different degrees, and in distinct locations.

A detailed overview of legislation relevant to e-waste up until 2009 has been covered in (Widmer & Lombard, 2005; Finlay & Liechti, 2008; Dittke, 2009). Dittke indicated that his report published in 2009 is outdated as there have been considerable updates and amendment to waste legislation since 2013 (Dittke, interview, 2018). Interestingly, there have been many new projects and studies on e-waste carried out recently in SA, yet there is no recent review of the legal frameworks focusing particularly on e-waste. Therefore, highlighting the need for this review. Furthermore, the report from 2009 is still widely and solely referenced in literature.

Dittke (interview, 2018), mentions that what has not changed over the last decade is that SA still does not have any dedicated legislation for e-waste. The possibility of this in SA does not seem realistic as it would entail having to amend the already amended NEMWA and NEMWAA, the Environmental Impact Assessment (EIA) regulations, as well as all the municipal waste management by-laws. However, what may help obtain clarity and focus in e-waste legislation, is the IndWMP for e-waste. Although the IndWMP would only be a form of quasi-legislation, it may help prevent issues such as lack of clarity, over-regulation as well as to promote industry self-regulation.

Overall, Dittke explains that waste legislation is fast-moving, and it is becoming stricter and more technically inclined. An example of this is displayed in the "National Norms and Standards for Disposal of Waste to Landfill" as published in 2013, specifically for hazardous wastes (Department of Water and Environmental Affairs, 2013). In the past, a simple classification of the hazardous waste was required before landfilling. However, now one would need to verify the classification through formal analysis with a chemical laboratory, which costs up to R30 000-40 000 for analysis. This highlights that more stringent legislation can often have financial or time costs for the waste industry due to tedious administration. Consequently, this may lead to non-compliance and illegal disposal in landfills or dumpsites.

5.3.1 Waste Management Licenses & Other Requirements

The licensing requirements for e-waste handling with regard to EIA and other regulations are listed in the legal document called "List of Waste Management Activities That Have, Or Are Likely to Have, A Detrimental Effect on The Environment" (Department of Water and Environmental Affairs, 2015). These requirements are usually further outlined in separate municipal by-laws (Dittke, interview, 2018). A summary of the licensing requirements for both general and hazardous wastes for different waste management activities are listed in Table 20.

E-waste recyclers need to apply for waste management licenses for various activities they perform such as storage, recycling, recovery, treatment and disposal of e-waste. Transportation is covered separately, usually by municipal legislation. Some of these licenses require EIAs to be conducted by external consultants, or simply to follow norms and standards set by the industry depending on activity and volumes handled.

Table 20: Summary of legislative requirements for waste management license for different waste categories according to activities performed (Department of Water and Environmental Affairs, 2015)

	Specific identification	Requirements	Additional Legislation
A	*General:* • Containment in excavations, dams, earth cells • Sorting, shredding, grinding, crushing, screening or bailing in operational area > 1000 m^2 • Recycling in operational area > 500 m^2, excluding that which is part of the manufacturing process on the same premises • Recovery, including refining, utilization or co-processing between 10-100 tons per day (monthly average) • Treatment in a facility with capacity between 10-100 tons • Disposal to a land area between 50-200 m^2 and total capacity < 25 000 tons *Hazardous:* • Recycling or recovery between 500-1000 kg per day (monthly average), excluding that which is part of the manufacturing process on the same premises • Treatment in a facility with capacity between 500-1000 kg *Waste Management Facility:* • Construction of facility for activities listed in Category A • Expansion or decommissioning of a facility for activities listed in Category A or B	Conduct a basic EIA	Environmental Impact Assessment Regulations section 24(5) of the National Environmental Management Act, 1998 (Act No. 107 of 1998)
	Specific identification	**Requirements**	**Additional Legislation**

B	*General:* • Recovery, including refining, utilization or co-processing >100 tons per day, excluding that which is part of the manufacturing process on the same premises • Treatment > 100 tons per day (monthly average) • Disposal to land area > 200 m^2, with total capacity > 25 000 tons *Hazardous:* • Storage and treatment in excavations, dams or earth cells • Re-use or recycling > 1 ton, excluding that which is part of the manufacturing process on the same premises • Recovery, including refining, utilization or co-processing between >1 ton per day, excluding that which is part of the manufacturing process on same the premises • Treatment > 1 ton per day (monthly average) • Disposal of any quantity to land *Waste Management Facility:* • Construction of facility for activities listed in Category B	Full scoping and impact reporting EIA	Environmental Impact Assessment Regulations section 24(5) of the National Environmental Management Act, 1998 (Act No. 107 of 1998)
C	*General:* • Storage at a facility of capacity > 100 m^3, excluding that in excavations, dams, or earth cells, or temporary storage *Hazardous:* • Storage at a facility of capacity > 80 m^3, excluding that in excavations, dams, or earth cells, or temporary storage	Comply with the relevant norms & standards	Norms & Standards for Storage of waste, 2013

The licensing requirements are divided into three categories according to the conditions necessary for the application of a waste management licence for specific activities. The activities highlighted in each category are storage, recycling, re-use, recovery, treatment and disposal of waste. Category A activities require a basic EIA to be conducted; Category B activities have a potentially greater environmental impact, due to higher volume thresholds or complexity of the activity, and therefore require a full scoping and impact reporting EIA; and Category C activities require compliance to norms & standards for storage of waste.

Additional regulations for waste management facilities will include occupational health and safety standards necessary for employee wellbeing. Specific standards for e-waste management activities can include ISO14001 which is a set of environmental management standards set by the International Organisation for Standardization (ISO) (International Organization for Standardization, 2015). Desco, a large e-waste recycler in Gauteng, has been certified for ISO14001 (Desco Electronic Recyclers cc, 2009). According to Karcher (interview, 2017), this is highly beneficial in order to partake in international trade. This is further confirmed by Averda (2018), in their summary of the requirements for import and export of hazardous wastes – see Table 21 in Section 5.3.4

The benefits of becoming fully legally compliant include standardised environmental stewardship, health and safety awareness, as well as credibility as an official industry operator. However, these benefits do not have perceived value to small-scale recyclers. There is therefore little incentive for them to see the process to completion, especially if they have successfully been operating under the legal radar for many years (Karcher, interview, 2017). The legislation thus requires reform if the objective is to promote smaller businesses to become part of the formal sector and encourage their growth.

5.3.2 Limitations Presented by Volume Thresholds, Administrative Time & Costs

E-waste defined as hazardous waste has been a contentious issue for a long time due to the limited volume thresholds (Karcher, interview, 2017). Volume thresholds for hazardous waste are much more conservative, a threshold up to 100 times lower, than for general waste for both category A and B activities. This threshold is very conservative considering the hazardous component of e-waste is very small relative to the weight of the device. Unfortunately, the legislation does not differentiate between hazardous and non-hazardous components and only applies to the whole device or load (Dittke, interview, 2018).

Karcher (interview, 2017) mentions that an official from the waste management department within the DEA, Anben Pillay, reported that the thresholds for processing hazardous waste before requiring a waste licence for category A activities might be lowered from 500 kg to 100 kg. This fact was further confirmed in a presentation given by Pillay at the Industry Waste Management Forum (Pillay, 2016). This potential revision is due to the fact that it is necessary for someone processing 100+ kg of arsenic to be licensed for environmental as well as health and safety precautions. However, dismantling a 100 kg batch of e-waste presents a negligible risk as compared to the handling of arsenic (Karcher, interview, 2017).

Furthermore, according to Karcher (interview, 2017), there needs to be some sort of discrimination in terms of the risk associated with the handling and type of handling of hazardous wastes, instead of blanket definitions and requirements. This should not only apply to e-waste but also any other specific hazardous waste types that only become hazardous when performing certain activities or at certain volumes. Although some sort of discrimination is made through the requirements at different volumes and activity categories, it remains far too generalised for the broad array of hazardous wastes.

Ultimately, a risk assessment will be conducted through the EIA process, however, a pre-screening of sorts may be helpful to avoid any paperwork, time and costs involved in EIA procedures. The ideal would not be to compromise on any environmental, health or safety regulations, but to encourage a more pragmatic and streamlined approach that is based on the actual risks involved.

Experts in the e-waste industry could assist in highlighting the risks associated with specific types of e-waste. This is particularly important for high-risk fractions such as radioactive and mercury-containing wastes, which was a concern for some recyclers. Ideally, the industry should be self-regulated through both risk- and activity-specific Norms and Standards, very similar to the recently published Ghana Technical Guidelines as mentioned in Section 4.2.1. Furthermore, this could be coupled with awareness initiatives and workshops educating recyclers and the general public about the high-risk fractions versus low-risk fractions, which is currently lacking in the industry (SA Metals Group, site visit, 2017; NC Electronix, interview, 2017).

Most small-to-medium recyclers process up to 500 tons per year, whereas thresholds limit volumes to 180 tons per year (500 kg per day) before a license is required (Lydall, Nyanjowa & James, 2017). The procedure to obtain waste licenses are both time-consuming and incurs a steep financial cost. Karcher (interview, 2013) explains that the cost for a waste licence depends on whether you are required to conduct a basic EIA or a full EIA, depending on activities and volumes. The EIA will cost about R90 000 - R150 000 to conduct through a third-party consultant. This is highly unaffordable to most small-to-medium recyclers due to their limited cash flows. Therefore, they remain "informal" or non-compliant and usually operate under the legal radar.

These regulations are in direct contradiction to the directive of stimulating enterprise development; the state should offer to carry such costs to stimulate the establishment of compliant businesses and thus create an enabling environment for entrepreneurs. The legislation thus requires reform in order to promote smaller businesses to become part of the formal sector and encourage their growth.

Furthermore, the turnaround time for obtaining the licence from the DEA, national government, is between 1-1,5 years. Category A activities only require a basic or condensed form of the EIA which can take up to 1-2 years depending on the province. This is due to factors such as the complexity of the situation as well as the efficiency of the provincial government in granting the relevant permissions. Category B activities require a full scoping EIA which can take up to 3-6 years. Once the EIA process has completed, only then will a waste licence be granted, and the activity can begin to be conducted (Dittke, interview, 2018). This creates a huge bottleneck for e-waste recyclers and often forces them into the status of illegitimacy or non-compliance. If discovered unlicensed, recyclers would face excessive fines.

One such e-waste recycler, Ecycle, was a dismantling company based in Paarl in the Western Cape. It was owned by a German national and employed about 15 people. The throughput of the business increased and exceeded 500 kg per day and thus required a license. After applying for a license with the DEA, Ecycle was fined R50 000 due to unlawful operation and was given no exemption. However, after paying the fine and hiring a consultant to assist in the license application, he declared bankruptcy and was forced to shut down. Karcher (interview, 2017) explains that this type of limitations and bureaucracy is a huge barrier to the industry.

Moreover, the waste licence is not linked to the waste management activity performed, but rather the location of the recycling facility. Furthermore, the location is required to be in an industrially-zoned area due to the nature of waste handling activities. Dittke (interview, 2018) explains that a licence is issued to a particular site because EIA's are site-specific. He adds that the site does not need to be rented or owned at the time of the EIA, however, lawful permission to access the site is required. This could be tricky as access may only be possible if the site is rented or already owned. This would cost the prospective recycler a hefty fee due to the long duration for the EIA to be conducted and permission to be granted, and this is highly impractical for small-to-medium recyclers starting up or wanting to relocate and expand their business.

Two recyclers namely, Reclite and Cape E-waste, both needed to relocate their operations due to the increased capacity of their operations. For Reclite, this was the third time they needed to relocate as their throughput kept increasing. This scenario seems to happen often in this industry. Dittke (interview, 2018) explains that relocation would entail an amendment to the waste licence and not an entirely new licence as was the initial concern. This might incur additional costs; however, he predicts that the costs would not be that huge. Dittke adds that due to the increase in operating capacity, the recycler might be changing from a category A activity to a category B activity. This would then require a new licence altogether due to the different EIA requirements. Dittke adds that if an additional activity is performed, this would also require a new licence.

In general, a licence can be amended for location and volume, however, not for activity or category thereof. Dittke (interview, 2018) also notes that the new or modified activity can only commence once the necessary permissions are granted. Application for an amendment to the waste licence should, in theory, take less time than that for a new licence altogether. But if the activity commences before permission is granted, a huge fine will have to be paid.

Careful planning and projections in business developments would thus be required for recyclers to remain within the legal constraints. Planned changes can prevent any fines and other legal consequences. However, the question is whether recyclers are informed about and understand the implications of all these constraints and requirements. Communication of waste legislation and its navigation is an important factor for the success of e-waste businesses. This could take the form of stakeholder workshops, notices, and handbooks. Currently, voluntary e-waste organisations such as SAEWA play a role in broadcasting updates in legislation and explaining legislative requirements to their membership (Karcher, interview, 2017).

5.3.3 Municipal By-laws

As previously mentioned, municipal waste by-laws provide specific requirements for waste contractors. Most municipal waste by-laws, particularly in metropolitan municipalities, require waste contractors to be registered with the relevant municipality in which they operate. This could mean multiple registrations if contractors are operating in multiple municipalities. This registration will cover the transport, but not the receiving facilities. Therefore, storage at a temporary holding site or handling facility would need to follow the relevant norms and standards. Furthermore, a waste license may be required for the handling of e-waste, which is informed by the type of activities conducted as well as the processing volumes.

Dittke (interview, 2018) explains that there are relatively few differences in the waste by-laws of the metropolitan municipalities such as Cape Town, Durban, and Johannesburg. All of them are phrased rather broadly in terms of the handling of e-waste, including transport, storage, and environmental protection. Generally, these metropolitans have more recent by-laws than the more rural municipalities. So, one might find from a regulatory perspective that there are more stringent requirements and paperwork in metropolitans compared to more rural municipalities.

An example of this is the City of Cape Town (COCT) Metropolitan Municipality Integrated Waste Management (IWM) by-law in which waste contractors are required to register with the COCT every two years. Businesses would, therefore, need to ensure their registration does not expire. Some municipalities may require re-registration every year, whereas others require a once-off registration or none at all. Additionally, the

COCT by-law also requires service providers to apply the waste hierarchy and practice waste minimisation and so forth. However, in a more rural municipality, this would not apply as their obligations are more basic. Dittke (interview, 2018) expresses that in his opinion these small differences would not deter anyone from wanting to operate in COCT or any other metropolitan area.

According to GreenCape (2018), there is the prospect of the Atlantis Special Economic Zone being a regional e-waste hub in the Western Cape. If the regional regulatory environment was favourable, this would attract more recyclers to operate in the Western Cape. However, Dittke (interview, 2018) explains, considering that they are all governed by the same national legislation, any regulations and any other sub-legislation would have to fall in line with NEMWA, whether its municipal by-laws or provincial acts. So, the general rule that any legislation that is passed down by a body lower than national – i.e. provincial or municipal – it can be made stricter but can never be more lenient than national acts (Dittke, interview, 2018). Therefore, national legislation should be principally consulted with regard to any barriers or enablers of the e-waste industry.

Dittke (interview, 2018) explains that duplication of legislation by national and municipal government departments has also been an issue. For example, the Gauteng province has a requirement that all hazardous waste contractors be registered with the provincial government. So, as a hazardous waste contractor operating in Johannesburg, Ekurleni, and Tshwane – three municipalities within Gauteng – one must be registered as a waste contractor with all three municipalities and in addition to the provincial government. Furthermore, if the hazardous waste contractor also has a temporary holding facility or a materials recycling facility, then NEMWA would apply, and one might need to get a waste licence. So, in total there is potential for five pieces of permissions one would need to get. This is an example of over-regulation, where administrative procedures would become tedious.

5.3.4 Other Relevant Legislation

Other legislation that may also be relevant is the Occupational Health and Safety Act (Act 85 of 1993) pertaining to workers safety and exposure to risks. Furthermore, the

Second-Hand Goods Act (Act, 6 of 2009), the Precious Metals Act (Act 37 of 2005) and the import and export regulations would also come into play (Dittke, 2009).

The occupational health and safety act has provisions for risk and hazard assessments to be conducted, use of personal protective equipment (PPE), as well as exposure control (Dittke, 2009). This will be required of all e-waste recyclers.

The Precious Metals Act will only pertain to recyclers who take part in the acquisition, possession, smelting, refining, fabrication, use and disposal of precious metals. This is will only be relevant if the recycler will be extracting metals from e-waste (Dittke, interview, 2018). Therefore, dismantlers and pre-processors of e-waste who are unlikely to take part in metal extraction will not need to consider this piece of legislation.

However, end-processors would be required to apply for a license from the South African Diamond and Precious Metal Regulator. Furthermore, if end-processors will be refining as well as conducting beneficiation activities, a license for these activities will need to be applied for from the Regulator (Dittke, 2009). Precious metals, in unwrought or semi-fabricated form, can only be sold to authorised dealers. These dealers require a permit from the Regulator in consultation with National Treasury and with the National Commissioner of the South African Police Service (SAPS) (Dittke, 2009).

The Second-hand Goods Act requires e-waste recyclers to register as second-hand goods dealers as well as recyclers who acquire second-hand goods with the SAPS. The intention of the Act and Regulations seems to be to control the dealing (and stealing) of second-hand goods and certain metal streams, and where this takes place for gain (i.e. in the sense of somebody selling something to another party). One of the aims of the Act is also to restrict the illegal sale of second-hand or stolen goods. This is why SAPS is the regulatory authority for this Act.

In terms of the Act, a “dealer” is defined as “a person who carries on a business of dealing in second-hand goods and includes a scrap metal dealer and a pawnbroker”. Furthermore, the Act defines “deal” as “includes acquire and dispose of”. This is very broad and does not differentiate between acquiring for free or for remuneration. Based on this definition, in Dittke’s opinion, centres accepting e-waste for free (i.e. without remuneration) would probably be excluded from the ambit of the Act. This refers to retailers or organisations who organise take-back schemes with no charge to donors.

Lastly, Dittke (interview, 2018) adds that on 30 October 2017, draft regulations regarding the import or export of both general and hazardous waste were proposed. These regulations are much the same as the guidelines presented by the Basel Convention. It outlines that the importer or exporter of waste would need importing and exporting permits from ITAC with prior consent from the DEA. Furthermore, the importer and exporter for hazardous waste specifically would need to fulfil various requirements as listed in Table 21.

It should be noted here that the procedures for international trade of raw e-waste or e-waste products are still not well defined or established in SA, specifically in relation to customs codes required (Karcher, interview, 2017). This results in difficulty in formulating and finalising the paperwork for international trade. However, there are laws in place which gives preference to local processors before granting export permits (SA Metals Group, site visit, 2017). This was in reference to copper exports; however, it is unclear whether this holds true for all products.

Table 21: Legal requirements for imports and exporter of hazardous waste in SA (Averda, 2018)

Legal requirements for the Importer	Legal requirements for the Exporter
Consent from the country of export	A cover letter (with the company's letterhead) indicating the type, quantity, country of origin and the reason for the export of the waste
A completed notification document	A completed notification document
Safety data sheets of the waste	Safety data sheets of the waste
Liability insurance	Liability insurance
Sales contract or agreement	Sales contract or agreement
Waste management license of the receiving facility	Any supporting documentation for the company receiving the waste, showing that they are permitted to handle waste (e.g. ISO14000, recycling certificate, etc.)
	Waste disposal permit or license

In summary, to fulfil all legal compliance requirements an e-waste recycler would need to:

i) Register in terms of municipal waste legislation for transporting and/or handling of e-waste;
ii) Apply for a waste licence from national government, as well as an EIA as required for the specific category of waste handling;
iii) Comply with the occupational health and safety act;
iv) Register as a second-hand goods dealer and/or recycler with SAPS;
v) Obtain licensing and permits in terms of the Precious Metals Act if they are extracting and/or processing precious metals from e-waste; and
vi) Obtain import and export permits from ITAC, if partaking in international trade of e-waste.

Overall, the legal requirements for e-waste handling might be overwhelming to the recycler as it requires consultation of a large collection of legislation, financial expenses, as well as time and administrative costs. Furthermore, the legal documents themselves are not always clear to persons without a legal background. Therefore, it should be stressed that consultation workshops and effective communication of legal requirements to the e-waste industry are necessary. This will improve instances of compliance and thus beneficial to government bodies in the long run in terms of monitoring and enforcement of legislation.

5.3.5 Monitoring & Enforcement of Legislation

The monitoring and enforcement of the relevant e-waste legislation are done through random inspections by government bodies. Alternatively, there could be an inspection based on reported suspicious activity or other evidence relating to undue illegal activities taking place (Dittke, interview, 2018). Legal consultants specialising in waste and environmental legislation would carry out these types of audits.

On a national level, the Green Scorpions might target specific industries and conduct random inspections. Dittke (interview, 2018) further explains that there is sometimes a difference in the level of enforcement of different provincial governments. The Western Cape and Gauteng provincial Department of Environmental Affairs are known to have a better system of enforcement compared to Eastern Cape and Limpopo, while Kwa-Zulu

Natal will fall somewhere in between. The same can be seen with different municipalities.

Lastly, voluntary industry organisations such as eWASA and SAEWA play a co-regulatory and monitoring role in legal compliance. It is in their interests to ensure best practices for the handling of e-waste is conducted (Karcher, interview, 2018).

5.4 Conclusion

Upon exploring the South African WEEEconomy, one gets a deeper understanding of the value chain activities, stakeholders involved, collection and value fraction distribution, technologies available, as well as the legislation and governance. These factors can all be seen in terms of either supporting and enabling, or creating a barrier, for the development of a secondary resource economy. A holistic view of all these factors is necessary when planning for local end-processing technology implementation and establishing local product markets.

6 Conclusions and Recommendations

The purpose of this research study was to develop a deeper understanding of how the e-waste industry is organised and investigate the key barriers and enablers to implementing local e-waste end-processing technologies. The investigation used desktop research together with qualitative data from industry experts and recyclers, which included interviews and site visits.

This chapter presents how each research objective was met, and recommendations for future research and development.

6.1 *Objective 1: Develop a deeper understanding of the development and organisation of the e-waste industry in SA.*

The first objective of the study was explored through two research questions. These questions explore the historical development of the industry and how the industry is organised and governed.

6.1.1 How has the e-waste industry historically developed in SA?

This question was explored in Chapter 4: Overview of South Africa's Waste Management System: History & Governance. This investigation into the historical development of SA's waste management system provided the much-needed insight into the current e-waste industry. The findings revealed that SA has progressive environmental and waste management legislation on par with international standards. However, this strict legislation soon became a hindrance for technology development and innovation of recycling initiatives due to the regulatory constraints and costs inhibiting the implementation thereof; originating from the legal definition of waste as an environmental liability instead of its true value as an untapped resource.

Chapter 4 also reveals that SA has long been using landfill as its primary technology for waste management. Although SA's waste policy promotes the waste hierarchy and circular economy principles, the reality on-the-ground, until very recently, still saw relatively low landfill gate fees, lack of separation-at-source initiatives, and low recycling rates. However, the informal sector took it upon themselves to fill the gap between the municipal service chain and the recycling value chain for many waste streams – e-waste is one of them.

SA now finds itself in a fast-changing waste landscape. Government is prioritising waste diversion from landfill through various mechanisms, such as landfill bans, investment of public funds for research and development of the waste economy. The economic and job creation potential have also played a part in this change. However, there are mixed opinions as to whether the industry can sustain itself given the costs involved in waste processing and compliance. In response to this, extended producer responsibility (EPR) and Industry Waste Management Plans (IndWMP) are in the process of being implemented for e-waste, paper and packaging, as well as lighting industries. This ensures the cost of recycling is subsidised and calls on a more structured waste management system in terms of collection and collaboration of industry operators.

The e-waste industry closely follows this development – being supported by an informal sector for collection; being hindered by strict waste legislation, and; awaiting EPR schemes in the form of IndWMPs to support industry growth.

6.1.2 How is the current e-waste industry organised and governed?

This question was explored in Chapter 5: Setting the Scene: South Africa's WEEEcosystem. In this chapter the e-waste industry was described in terms of the quantities and flows into, around and out of the country; the value chain and stakeholder relationships were mapped; and the governance of the industry was further examined.

The findings to this question revealed that although there is a demand for e-waste recycling due to the growing volumes of e-waste generated and the potential value of the materials, the exact quantities cannot be accurately evaluated due to limited and incomplete waste data available. Estimations using import and sales data predict more than 300 000 tons of e-waste was generated in 2016. Of which only 11% was recycled in SA. There is thus a need to track e-waste generation and recycling data through development and implementation of mandatory waste information systems, as well as unlock greater volumes of e-waste for recycling.

The mapping of the stakeholder network and the e-waste value chain revealed that the extent of material recovery from e-waste in SA is limited to collection, dismantling and sorting. While end-processing happens in European countries who import the metal-rich, value fractions. Furthermore, a hierarchy of recyclers exists within the value chain, starting with the informal waste pickers who sell their fractions to smaller recyclers, who then sell their fraction to larger recyclers, who then sell their fractions overseas.

Lastly, the governance of the e-waste industry is examined more closely in relation to location, capacity and compliance requirements for e-waste recyclers.

Overall, objective 1 was fully met and provided a clear grounding in the organisation of the e-waste industry in SA, which was necessary to fulfil the subsequent objectives.

6.2 **Objective 2:** Investigate existing technology options for e-waste end-processing.

6.2.1 What are the existing technology options for e-waste end-processing?

Existing technology was explored in the literature review, Section 2.3: E-waste Processing Technologies. This exercise revealed that technology options for e-waste end-processing, which is mainly metal recovery processing, often results in a comparison between pyrometallurgy and hydrometallurgy. However, the successful implementation of these technologies is largely dependent on the context in which they operate. Pyrometallurgy is often associated with large scale smelting operations for metal-rich e-waste fractions, sometimes in conjunction with traditional mineral ore processing for metal extraction. While hydrometallurgy is favourable for small-scale operations for metal recovery. Hydrometallurgy is also used for final product refining in both cases.

The implementation and feasibility of some of these technologies in the SA context were explored in Section 5.2.3: Technologies used for E-waste Processing. Some of the factors considered were economies of scale, health and safety of the operation, accessibility to small recyclers and environmental implications.

This objective was fully met; however, it should be noted that this examination did not result in a clear answer as to what technology should be implemented in SA. Rather, it provided insights into what should be considered for implementation in the local context.

6.3 **Objective 3:** Identify the socio-economic and legal legislative barriers and enablers for local, small-scale end-processing for value extraction from e-waste.

6.3.1 What contextual factors affect the implementation of e-waste end-processing technologies in SA?

This objective was explored throughout Chapter 5: Setting the Scene: South Africa's WEEEcosystem, in relation to the e-waste volumes and flows, the e-waste value chain, technology options, as well as governance. A summary of the barriers to local end-processing of e-waste in SA is illustrated in Figure 22 and further described here.

The e-waste value chain in SA mainly focuses on collection, dismantling and initial processing in preparation for export. The collection network and infrastructure are currently supported by informal waste pickers and small to large recyclers who provide a diversity of collection strategies and a wide network of e-waste sources.

However, volumes are still largely unreliable in terms of fluctuations throughout the year, resulting in financial and job insecurity, especially for small to medium recyclers. This is largely due to inaccessible volumes such as that in landfill or storage. The root cause of this the lack of awareness and engagement of civil society in using the correct channels to recycle their e-waste. Another factor to consider is the inability to predict volumes due to the incomplete waste data and non-compliance regarding waste information systems.

The availability and quality of feed and the development of local end-processing and manufacturing capacity are co-dependent. On the one hand, implementation of technologies at the economies of scale required is only possible with sufficient e-waste volumes. On the other hand, the expansion of the industry to end-processing will encourage an improved and robust collection infrastructure to obtain necessary volumes. Therefore, these two factors need to be dealt with simultaneously to ensure the sustainability of the industry.

E-waste usually gets collected by smaller agents or drop-off sites, thereafter the 'cherry-picked' value fractions get passed on to larger dismantlers and pre-processors. Larger recyclers act as consolidators and ultimately distributers of value fractions to international companies for further processing. High-value metal fractions, including PCBs and phosphor powders, are exported to large European smelters. Some ferrous and non-ferrous metals are processed locally at foundries, while plastics are sent to Asian countries. Other fractions such as glass, batteries and some phosphor powders are stockpiled while processing routes are being developed and researched.

The practice of value fraction export for further processing is comparable to that of the minerals processing industry in SA. This practice perpetuates the best-of-two-worlds philosophy, which is based on the belief that end-processing in emerging and developing economies will always be sub-par to the international standard in terms of health, safety and environmental risks.

Furthermore, there are high legal barriers for precious metal refining and trade. Therefore, process development and research for metals extraction remain exclusive to existing metal refineries. Legislation, together with large capital and research investment creates a barrier to innovation for SMEs in the sector. Additionally, there is an overall lack of local product markets and manufacturing capacity, which is also true for other e-waste value fractions such as plastics, glass and batteries.

Although there is no commercial-scale end-processing technology available in SA, SA Precious Metals developed a hydrometallurgical technology for metal extraction from PCBs, with a daily capacity of two tons. It is unclear whether this technology is financially competitive with international smelters. Furthermore, this technology remains exclusive and inaccessible to smaller recyclers due to a minimum processing volume requirement of ten tons of high-grade PCBs. It further propagates the culture of cherry-picking, leaving the non-viable fractions or residues left for disposal elsewhere. Other issues such as cash flow and transportation costs also arise.

Objective 3 was fully met and summarised in Figure 22.

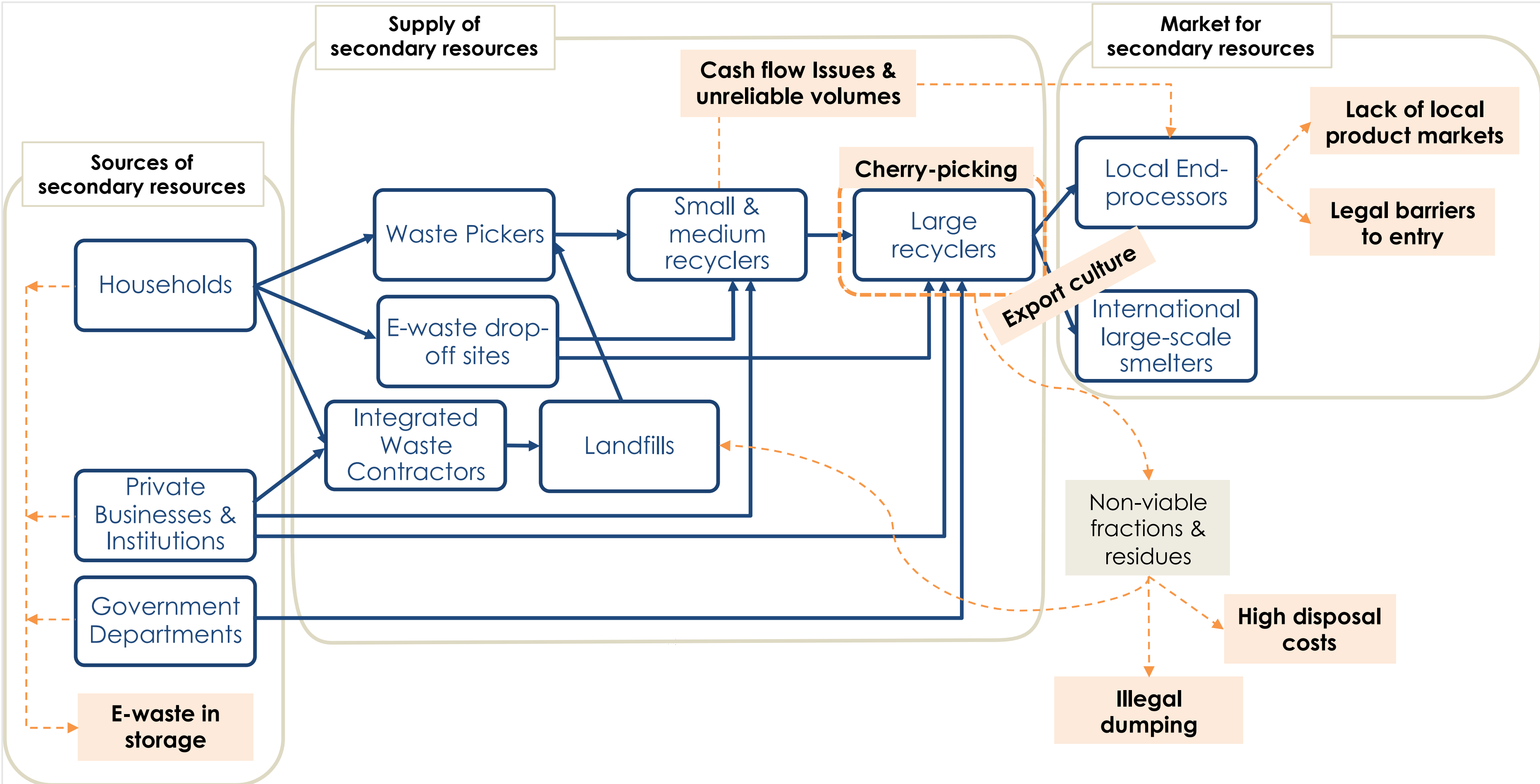

Figure 22: Summary of barriers to local end-processing of e-waste in a secondary resource economy

6.4 **Objective 4:** Provide recommendations for the next steps in establishing local e-waste end-processing further research and development, addressed to research institutions, industry and relevant government bodies.

6.4.1 How can research institutions, industry and relevant government bodies address these factors?

For the e-waste industry in SA to develop and implement local end-processing technology, and, in turn, progress towards a local secondary resource economy, interventions in the following areas is required:

i) Collection and increased access to e-waste volumes,
ii) Technology investment and implementation for small-scale end-processing, and solutions for low-value fractions
iii) An enabling legislative environment, and
iv) Increased market opportunities.

These interventions require commitment from each of the relevant stakeholders, namely, industry practitioners, government bodies and researchers. The recommended commitments are presented as follows.

6.4.1.1 For industry practitioners

Industry practitioners include all those along the value chain, starting with the waste pickers and ending off with manufacturers and end-use markets for e-waste fractions. The first intervention to increase collection and access to e-waste volumes will require awareness-raising activities to mobilise consumers. This can be promoted by the industry themselves by marketing their collection activities and possibly providing incentives where possible.

The informal waste pickers and smaller recyclers or dismantlers make up a significant part of the collection infrastructure yet are the most marginalised. They should be supported in their activities in the form of access to stored e-waste volumes and facilities to support their collection and sale of e-waste, such as ablution facilities, areas to handle their waste volumes and access to buyers. Additional support to facilitate their growth may include upskilling in refurbishment and sale activities which will help diversify and strengthen their income potential. This support can be provided by larger recyclers as well as the waste department in municipalities.

Collection can also be reinforced by leveraging existing resources the existing municipal waste collection infrastructure which involves various private waste contractors servicing households part of separation-at-source pilot projects. These contractors can provide an additional source of e-waste for e-waste recyclers. Networks such as IWMSA, RAG, and the plastics and scrap metal industries can also be explored as potential sources of e-waste.

The second intervention into technologies suitable for the SA context should be explored with the small to medium recyclers in mind. These recyclers require new business models to allow ease of cash flow and rental, or servicing, of end-use processing technologies. This can be achieved through agreements between local end-processors and small to medium recyclers who cannot afford the capital cost of technology investment.

Industry should also look into investment into technologies for low-value fractions as well as end-use markets for e-waste fractions to support the sustainable development of the local industry.

Industry networks can support the third intervention of an enabling legal environment by providing recyclers with current best practices and updates in legislation, as well as credibility or a 'social license to operate'. They should also play the role of guiding policy development by communicating industry needs, especially from the informal sector and smaller recyclers, to government bodies.

6.4.1.2 For governments and policymakers

The relevant government bodies include the Department of Environmental Affairs (DEA), the Department of Science and Technology (DST), as well as the Department of Trade and Industry (dti). Currently, it is unclear how these national departments are collaborating in their efforts to support the e-waste industry. These departments seem to have a similar goal of diverting waste from landfill while supporting industry development. However, the conflict between defining waste as both an environmental liability as well as a valuable resource needs to be addressed by all three departments.

The DEA plays an important role in creating an enabling legal environment for e-waste end-processing. This can be in the form of specific legal permissions for innovation and pilot projects without the accompanying administrative costs. This should be aligned with the DST efforts to financially support the research and development of the e-waste sector. While the dti's role would be to promote end-use markets for e-waste fractions and providing incentives to support local industry as opposed to exporting e-waste fractions for processing elsewhere.

This inter-departmental collaboration is also needed for the success of the Industry Waste Management Plans (IndWMP) through EPR schemes. The EPR schemes could be further supported with tax incentives for companies investing in end-processing technologies for local e-waste fractions, particularly for low-value fractions. This will help develop local industry but also discourage cherry-picking and ultimately prevent low-value fractions from going to landfills or dumpsites.

The DEA is also required to support the application of waste information systems to track e-waste generation and recycling trends. This will provide an evidence-base to plan and guide industry development.

6.4.1.3 For research institutions

Finally, local research into technologies suited to the South African context should be further supported. Research can include technical, socio-economic and legal feasibility studies accompanied by pilot tests is recommended. Topics including new business models, small-scale, mobile and modular technologies, as well as technology implementation strategies, are required. Furthermore, policy strategies to steer e-waste management and governance towards developing a circular economy for e-waste is also recommended.

Objective 4 was met by addressing the barriers that were discovered in Objective 3 and addressing recommendations to each of the three stakeholders separately.

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Appendix A: Sample interview questions

Materials received and produced

- What types of e-waste do you deal with?
- Do you deal with any hazardous substances? If so, what is it and what type of e-waste devices does it come from?
- What waste streams do you have? How do you manage your waste streams?
- What product streams do you produce?
- Where do you sell your products?
- What/who are your sources of e-waste (e.g. public or private sector, households, etc.)?
- What is your average annual volume of e-waste handled?
- What type of device do you receive the largest volumes of?

Technology & Operations

- What e-waste management activities do you do?
- Describe your e-waste collection infrastructure and logistics.
- Have your business/operations grown over the years you have been operating? Elaborate on the possible reasons for this.
- What sources of income do you have?
- How large is your collection radius?
- What technology do you use?
- How many employees do you have and how are they organised?
- Do you have plans for growing your business? If so, what are they? If not, why?
- How do you communicate with your clients (buyers/ sellers)?
- How do you attract new clients (buyers/ sellers)?
- How is your financial/ business model structured?
- If you could have anything to improve your business operations, what would it be and why?
- Describe the initial steps you took to start up your business.
- What skills did you require to start and maintain this business?
- What skills did you develop through running your business?
- What health and safety procedures do you follow?

- Do you have any traceability procedures to keep track of devices from collection to the time it leaves you?

Trade & legislation

- Do you have any issues with the current legislative framework? If so, what are they?
- If you could change any part of the policy and legislative framework regarding e-waste, what would it be and why?
- What trade regulation sod you currently deal with?
- What was the first legal steps you followed to set up your business? Describe what the experience was like.

Please note: the interview structure varied from interview to interview depending on the flow of discussion. The interviewer left room for personal experiences of the interviewee to come up and for them to lead the discussion. Therefore, the above questions did not always follow this order and all of the questions was not always asked. Follow-up interviews was scheduled in order to obtain missing information, given the availability of the interviewee. Face-to-face follow-up interviews is preferable; however, telephonic and email interviews was mostly done depending on the availability and preference of the interviewee/research participant.

Appendix B: Photographed Samples of Steps in Data Analysis

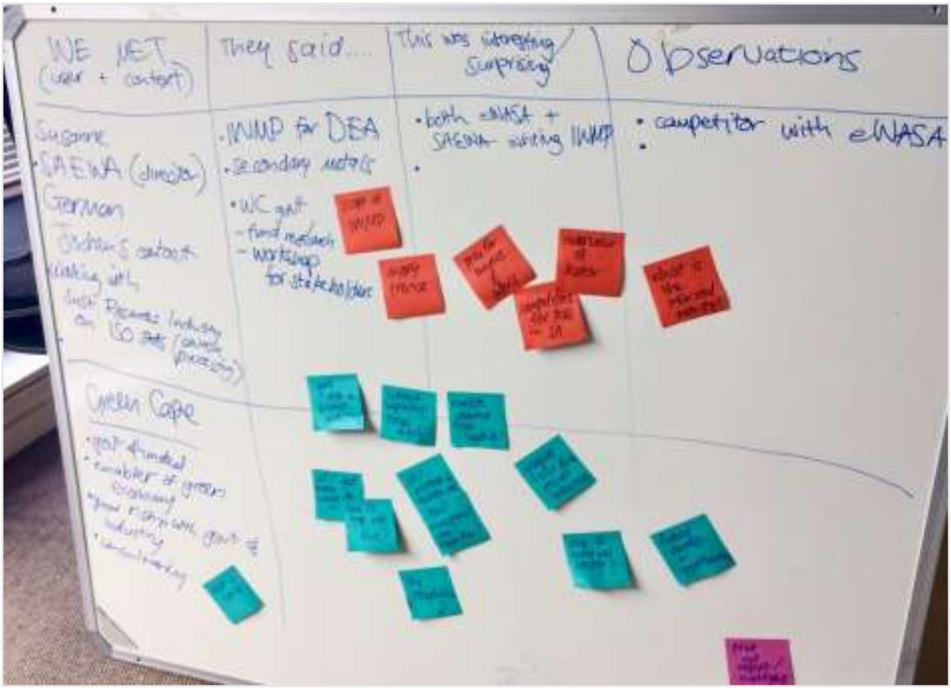

Figure 23: Photograph of interview unpacking matrix done in a group of three

Figure 24: Photograph of theme grouping done in a pair

Appendix C: Ethics Clearance Certificate

Application for Approval of Ethics in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/ebe/research/ethics1

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Zaynab Sadan
Department		Chemical Engineering
Preferred email address of applicant		Sdnzay001@myuct.ac.za
If Student	Your Degree: e.g., MSc, PhD, etc.	MSc
	Credit Value of Research: e.g., 60/120/180/360 etc.	180
	Name of Supervisor (if supervised):	Prof. Jochen Petersen (primary supervisor); Prof. Dee Bradshaw (co-supervisor)
If this is a researchcontract, indicate the source of funding/sponsorship		N/A
Project Title		Evaluating Opportunities within the E-waste Recycling Economy in South Africa

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

SIGNED BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Zaynab Sadan	signature removed	**17 Sep 2017**

APPLICATION APPROVED BY	Full name	Signature	Date
Supervisor (where applicable)	Prof. Jochen Petersen	signature removed	19-Sep-2017 ~~Click here to enter a date.~~
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section1; and for all Undergraduateresearch (Including Honours).	Click here to enter text.		Click here to enter a date.
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.	Roger Behrens	signature removed	02 Nov 2017

Appendix D: Table of E-waste Initiatives

Table 22: E-waste Initiatives

Name	Type of Initiative	Description of Role & Activities	Date Formed
WEEE Africa Forum	A joint venture of leading African take-back systems for Waste Electrical and Electronic Equipment (WEEE) and batteries.	WEEE Africa Forum provides a platform for responsible producers and organisations to take on the challenge of electronic and electrical waste in Africa. The point of contact for manufacturers, online retailers, importers and exporters of electronic goods and batteries.	2018
Southern African E-waste Alliance (SAEWA)	Voluntary e-waste management structure	A non-profit organisation which helps to coordinate responsible management of e-waste in a one-stop shop format nationwide (and beyond). The e-Waste Alliance is made up of independent business partners who are able and willing to work together in symbiotic working agreements to handle all parts of the e-waste stream in the most integrated and value-added manner and according to the best technologies locally available while assuring safe data destruction at all times.	2009
e-Waste Association of South Africa (eWASA)	Voluntary e-waste management structure	A non-profit organisation working with manufacturers, vendors and distributors of electronic and electrical goods and e-waste handlers (including refurbishers, dismantlers and recyclers) to manage e-waste effectively in SA.	2008

Name	Type of Initiative	Description of Role & Activities	Date Formed
E-waste Recycling Authority (ERA)	Producer Responsibility Organisation (PRO)	A Product Responsibility Organisation to regulate and develop a progressive E-Waste industry in South Africa with the objective of ensuring that South Africa has an effective and sustainable E-Waste Management System and Plan.	2014
E-waste Implementation Toolkit (EWIT)	Free online resources on e-waste management best practices	The web portal offers guidance and a practical support for the design and development of e-waste collection and recycling systems.	2014
Institute of Waste Management of Southern Africa (IWMSA)	Voluntary waste management structure	A multi-disciplinary non-profit association that is committed to supporting professional waste management practices. IWMSA contributes to the improvement of waste management standards and legislation, support international, national and regional trends in best environmental practices; promote the science and technology of waste management and practice affordable cost-effective management of waste.	1976
Waste Management Bureau (WMB)	Governmental waste management body	The DEA has established the Waste Bureau in terms of section 34A (1) of NEMWA. One of its functions is to support and advise on the development and implementation of Industry Waste Management Plans.	2017
Recycling Action Group (RAG)	Packaging industry network	An association of like-minded organisations who are also involved in the recycling and recovery of primary packaging raw materials. The members of the group comprise of representatives from the various recycling organisations as well as the Packaging Council of South Africa (PACSA).	Unknown

Name	Type of Initiative	Description of Role & Activities	Date Formed
Metals Recycling Association of SA (MRA)	Scrap metal industry network	Assisting business and law enforcement through the introduction of anti-theft measures; co-operating with consumers to ensure that local industry requirements are met; Ensuring that government's legislative initiatives are correctly researched; Promoting the positive contribution of the metal recycling industry. Safety, health and environmental issues relating to the industry; Ensuring that members' businesses are conducted in an environmentally friendly manner; Policing members' adherence to the association's code of conduct; Ensuring members conduct their businesses in accordance with all applicable government, provincial and local legislation.	1942
National Recycling Forum (NRF)	A non-profit organisation created to promote the recovery and recycling of recyclable materials in South Africa	Provides a national communication forum for key players in the field of recycling; interacts with central and provincial government to encourage the recycling of waste; facilitates the formation of regional forums that draw their memberships from enthusiastic and interested volunteers as well as small recyclers; encourages the establishment of buy-back centres and drop-off points through the activities of its members in the various centres	Unknown
Western Cape Industrial Symbiosis (WISP) developed by GreenCape	Free facilitation service to businesses.	WISP facilitators provide our business members with dedicated time and technical expertise, connecting companies with unused or residual resources such as materials, energy, water, assets, logistics and expertise	2013