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Optimization of Waste Reduction in the Construction Sector: The Case study of the eThekwini Municipality in South Africa

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Giselle Pillay

216029950

Supervisor: Prof Cristina Trois

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DECLARATION

As the candidate's supervisor I agree to the submission of this dissertation

....

Prof. Cristina Trois   Date

I .... declare that:

i. I accept the rules of assessment of the University of KwaZulu-Natal and the consequences of transgressing them.

ii. This entire research project, entitled 'Optimization of Waste Reduction in the Construction Sector: The case study of the eThekwini municipality in South Africa' is wholly my own. The research project reported here was carried out completely within the institution, in the department of Civil Engineering, under the supervision of Prof. Cristina Trois in partial fulfilment of a Master of Science in Engineering in the Waste and Resources Management Programme. This research project has neither in part, nor as a whole been submitted to another university.

iii. The author of this dissertation has made use of the WROSE^{TM} Model for data analysis and recommendations. It is understood and accepted that the WROSE (Waste to Resource Optimisation and Scenario Evaluation) Model is a licensed trademarked Waste Management Decision Support model/tool developed by UKZN (Prof. Cristina Trois) since 2010. This may include further know-how and intellectual property.

iv. The author of this dissertation undertakes to not disclose and/or reproduce and/or publish and/or use of any aspect of the WROSE model, now and in the future, in part or in full, including the input and output data of this study, outside of this document without the consent, in writing, of Prof. Cristina Trois or a person so appointed or elected by UKZN/Prof. Trois.

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Giselle Pillay   Date

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ABSTRACT

Although South Africa is on the road to a greener future through the Act No. 26 of 2014: National Environmental Management: Waste Amendment Act 2014, the South African Waste Report (Department of Environmental Affairs, 2018b) states that in 2017, 48% of the overall construction and demolition waste was landfilled. This percentage indicates that an extensive quantity of valuable and recyclable construction and demolition (C&D) waste is disposed to landfills or utilized in insignificant applications. The eThekwini Municipality, the third largest municipality in South Africa, has diminishing airspace of its landfills. Construction and demolition waste consumes approximately 40% of eThekwini Municipality's landfill airspace. The Integrated Waste Management Plan of Durban Solid Waste Unit (DSW) of the eThekwini Municipality does not include a specific construction and demolition waste management strategy. Therefore the eThekwini municipality was chosen as the case study for this research. The Waste and Resource Optimisation Scenario Evaluation (WROSE) model is a decision-making tool that was developed in South Africa by UKZN to enable municipalities to optimise their waste management strategies. This study aims to establish the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in the eThekwini Municipality as well as to expand the WROSE model to include different C&D waste management strategies. The literature review showed the relevance of research, critically evaluating the waste management strategies that are practiced internationally and nationally. This was followed by a waste stream analysis of DSW's weighbridge data. This data was utilized in the creation of valorisation scenarios for C&D waste, which were inputted in the WROSE model. Various scenarios were investigated to determine sustainable management of C&D waste that included landfilling, landfilling with recovery of rubble for creation of access roads in landfills; 50% diversion from being landfilled and recycling of the aggregates by DSW; as well as 65% diversion and recycling by a specialised company. Analysis of the weighbridge data indicated that approximately 40% of the eThekwini municipality's MSW is C&D waste, with builders rubble increase rate of 1000 tons per year and Sand and Cover material increase rate of 10 800 tons per year. The WROSE outputs included Landfill Space Savings, Job Creation Potential and Economic Feasibility of the scenarios analysed. The analysis conducted using the WROSE Model show that a total of 3 300 000 m^3 of landfill airspace can be saved, 59 jobs created, and R 108 000 000 generated at Buffelsdraai and Lovu landfills over the next ten years. Implementing the scenarios and recommendations displayed in this study will aid the eThekwini municipality in finding a solution to the diminishing landfill airspace problem and overall improve society by saving valuable natural resources, creating jobs and uplifting the community.

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LIST OF ABBREVIATIONS

C&D – Construction and Demolition

DEA - Department of Environmental Affairs

DSW- Durban Solid Waste

DWAF - Department of Water Affairs and Forestry

GHG - Greenhouse Gas

HA – Hectares

HRB-Highway Research Board

IWMP - Integrated Waste Management Plan

MSW - Municipal Solid Waste

NEMA - National Environmental Management Act

UKZN- University of Kwa-Zulu Natal

WROSE – Waste Resource Optimisation Scenario Evaluation

CHAPTER 1

1. INTRODUCTION

1.1 Background

For many years the construction industry has been operating in a linear process by which natural resources are sourced and processed to establish the end product. By-products formed during processing are known as construction waste. Under ideal conditions, the supply of natural resources is infinite, with a boundless landfill capacity. On the contrary, natural resources are becoming progressively scarce, and landfills are rapidly reaching capacity (Delaware, 2003).

The construction industry has one of the most significant impacts on the natural resources and energy of the world, as 60% of worldwide consumption of the Earth's raw natural resources are consumed by the construction and civil works industries. The global production of concrete was set to the extent of 16 billion tonnes by 2010 (Immelman, 2013).The failure to recognize the consequences of economic development has caused a worldwide environmental catastrophe due to negligent material resource management. Therefore, research is being conducted continually throughout the globe to manage material resources efficiently and develop Construction and Demolition waste prevention and minimization schemes (Osmani and Villoria-Sáez, 2019).

Research has shown that through various methods, waste can become valuable again and can be treated as a resource. A globally used evaluation process tool, known as the Waste Hierarchy, displays the steps involved for sustainable waste management (Ferrari et al., 2016). Local research conducted at the University of Kwa-Zulu Natal (UKZN) has developed the WROSE model (Waste to Resource Optimisation and Scenario Evaluation) (Trois and Jagath, 2011, Trois and Kissoon, 2019, Kissoon and Trois, 2018) a waste management decision-making tool that provides a methodology for municipalities to evaluate and optimize their waste management strategies to achieve a fully integrated system.

South Africa, more so the eThekwini Municipality, is currently on the verge of a crisis due to the diminishing airspace of landfills (Moodley et al., 2019). In South Africa, 48% of all construction waste ends up in landfills (DEA, 2018a). Hence, diversion of construction and demolition waste from landfill sites is essential. The eThekwini municipality was chosen as the case study due to its problem of diminishing landfill airspace as well as it being one of the largest cities in South Africa, hence the waste generated could be considered representative of South Africa. As there is inadequate data available for Construction and Demolition waste in South Africa, there are limited waste management practices of this waste. This research aims to establish the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in the eThekwini Municipality as well as to expand the WROSE model to include the different C&D waste management scenarios.

1.2 Rationale of study

Construction and Demolition waste consists of both builder's rubble, sand and cover material. The Cleansing and Solid Waste Unit of eThekwini Municipality, Durban Solid Waste (DSW) classifies Builder's Rubble, Sand and Cover material separately. Builders rubble's consists of large particle sizes of bricks, concrete, scrap metal and wood that comes from the construction or demolition of an infrastructure. Currently portions of sand and cover material waste that enters the DSW landfills is used for daily covering of the landfilled waste, instead of importing cover material, a 200 mm cover is used at the end of every day operation. Once the landfill site reaches its capacity and no longer needs daily covering, sand and cover material still enters landfills which then takes up large amounts of landfill airspace. This study will focus on using builders rubble, sand and cover material that enters the DSW landfills as a resource. In terms of builders rubble, this study will focus on recycling concrete and masonry as it takes up 69% of the construction and demolition waste composition, according to the State of Waste Report (DEA, 2018b). Other C&D waste such as wood, metal, gypsum, plastic and miscellaneous materials contribute to a small amount of overall C&D waste generated which is not to be considered in this study.

Previous research has been conducted by the UKZN and the Transport Department whereby a green pavement was generated with the use of builders rubble, sand and cover material. Sand and cover material was used as a blending agent with the crushed aggregates to make a product such as a sub-base material. The previous research verified that Construction and Demolition waste can replace G6 and G5 natural aggregates which is utilized in sub base and sub grade layers in road construction in accordance with the South African pavement design criterion. The recycled aggregates in the previous study was classified as A1a, which is the best option, in the Highway Research Board (HRB) classification (Zedda et al., 2014). This research aims to build on previous research by completing a WROSE Model analysis of various C&D waste management scenarios, whereby some of the scenarios include the recovery of C&D waste to substitute recycled content for virgin materials, through the utilization of a crusher.

1.3 Motivation for the study

The construction industry plays a vital role in the contribution to the total waste produced in South Africa. According to the South African State of Waste Report (DEA, 2018b), the construction sector contributes 8,1% to the overall waste produced. Due to the sudden increase in the construction sector, the increase in the general waste generation between 2011 and 2017 for the construction industry is 639% (DEA, 2018a). This significant rise in Construction and Demolition waste places immense pressure on South African landfills. As landfilling of waste is a relatively inexpensive method to dispose of waste, South African landfill sites have become exhausted, forcing many landfills to stop operations. Landfilling has adverse effects on the environment, economy, and social aspects. When a landfill closes, waste is diverted to other landfills. Therefore vehicles have to travel further to the alternate landfills, which in turn causes an increase in the cost of dumping, which leads to increased illegal dumping, hence increased levels of environmental pollution (Moodley et al., 2019). Thus utilizing construction waste as a resource to divert this waste from landfills is necessary.

Recovery and recycling of construction waste can be economical and could potentially become another source of income. The production of virgin materials puts a strain on natural resources. The reduction of virgin resources drastically lowers the carbon footprint of the construction company. Despite the implementation of the Act No. 26 of 2014: National Environmental Management: Waste Amendment Act, 2014 (DEA, 2014) there is still a lack of progress in the construction waste as according to the South African Waste Report: Construction and demolition waste recovered/recycled is only 52%. Hence, there is still room for improvement with the insertion of proper waste management strategies in the construction and demolition waste sector. 48% is a considerable quantity of construction and demolition waste disposed into landfills; this research will aim to develop effective construction and demolition waste management practices. Figure 1.1 shows the large amount of landfill airspace construction and demolition waste occupies.

Figure 1.1 Construction and Demolition waste at landfill Source: (Pradeep, 2017)

1.4 Research question

What is the best recovery system for Construction and Demolition waste within the eThekwini Municipality?

1.5 Research gaps

The main research gaps identified were that the eThekwini municipality in South Africa has diminishing landfill airspace. Construction and demolition waste needs to be diverted from being landfilled due to it being dense and bulky, which causes it to occupy a significant amount of airspace in the landfill. Currently the Integrated Waste Management Plan of the eThekwini Municipality does not include a specific construction and demolition waste management strategy. Therefore construction and demolition waste is being landfilled with little to no recovery.

The WROSE Model generates scenarios which include waste being used as a resource. The WROSE Model has created various optimization scenarios for various waste streams such as food waste , garden waste, plastic waste and many other waste. The WROSE Model has not yet developed a specific scenario for construction and demolition waste management. The aims of this research arise to find solutions to the various research gaps uncovered.

1.6 Aims

This study will contribute to the cause of preserving landfill airspace by utilizing waste as a resource, hence diverting waste from being landfilled. Therefore the study has the following aims:

- To establish the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in the eThekwini Municipality, South Africa.
- To expand the WROSE model scenarios to include the different C&D waste management and valorisation strategies.

1.7 Objectives

The aims mentioned above will be achieved by accomplishing the following objectives listed below:

- Review the literature on waste management strategies for C&D waste implemented in South African Municipalities.
- Identify challenges in the sustainable management of C&D waste in the eThekwini Municipality.
- Define and Evaluate WROSE model indicators of sustainability for assessing the waste management scenarios .
- Analyse the eThekwini Municipality as a case study for C&D waste management.
- Waste stream analysis at eThekwini municipality using weighbridge data
- Develop improvement scenarios for C&D waste in the WROSE model
- Determine the most feasible scenario upon specific indicators of sustainability

1.8 Methodological approach

This research consists of the modelling of zero waste strategies for C&D waste, with the use of the eThekwini municipality as the case study. The strategy identified was recycling. The model utilized in this research was the WROSE Model, developed by UKZN. The WROSE Model output shows the impact of waste management scenarios in terms of environmental, economic and socio-economic indicators. The indicators include that of Landfill Space Savings, Job Creation Potential and Economic Feasibility. The WROSE Model outputs are able to achieve the aim of this research which is to determine the most economical, social and environmentally feasible C&D waste management practices for implementation in the eThekwini municipality, South Africa. A literature review was completed to determine the significance behind the research by examining literature relevant to the topic, to gather critical information to meet the objectives of this research. This literature review critically evaluated the current worldwide C&D waste management strategies. A case study of the eThekwini municipality was carried out in this research. SandOp Recovery World was identified as a private company in eThekwini, whose expertise lie in recycling C&D waste into high value aggregates, were also investigated to gain insight on the practises of recycling C&D waste. A quantitative approach was utilized in the case study of the eThekwini municipality's landfill sites, as the C&D waste was quantified through obtaining the weighbridge data and interviews were conducted with DSW's landfill personnel to investigate the management of C&D waste at eThekwini landfill sites and at the aggregate recovery company called Sandop Recovery World, to gather an understating of the recycling options for this waste stream. Once the status of C&D waste in the eThekwini municipality was established through a fieldwork waste stream analysis of weighbridge data, appropriate waste management scenarios were developed as and evaluated using the WROSE Model. The scenarios were evaluated using a set of sustainability indicators and the best scenario determined for implementation. Figure 1.2 outlines the structure of the methodological approach.

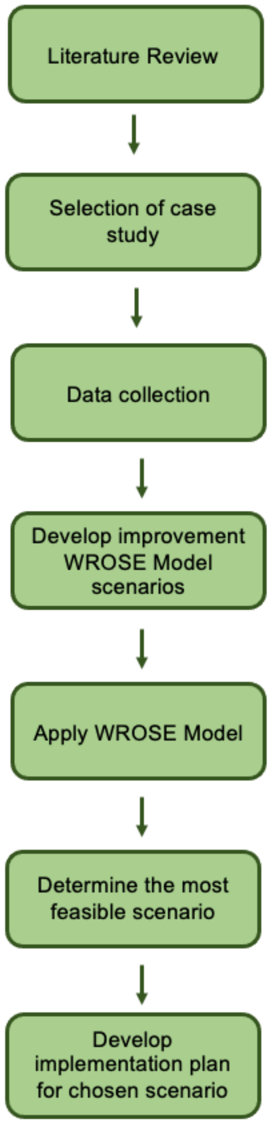

Figure 1.2 Methodological approach of the research.

As the methodology is centred around achieving the various aims and objectives of this research, Figure 1.3 shows a framework of the connection between aims, objectives and the methodology.

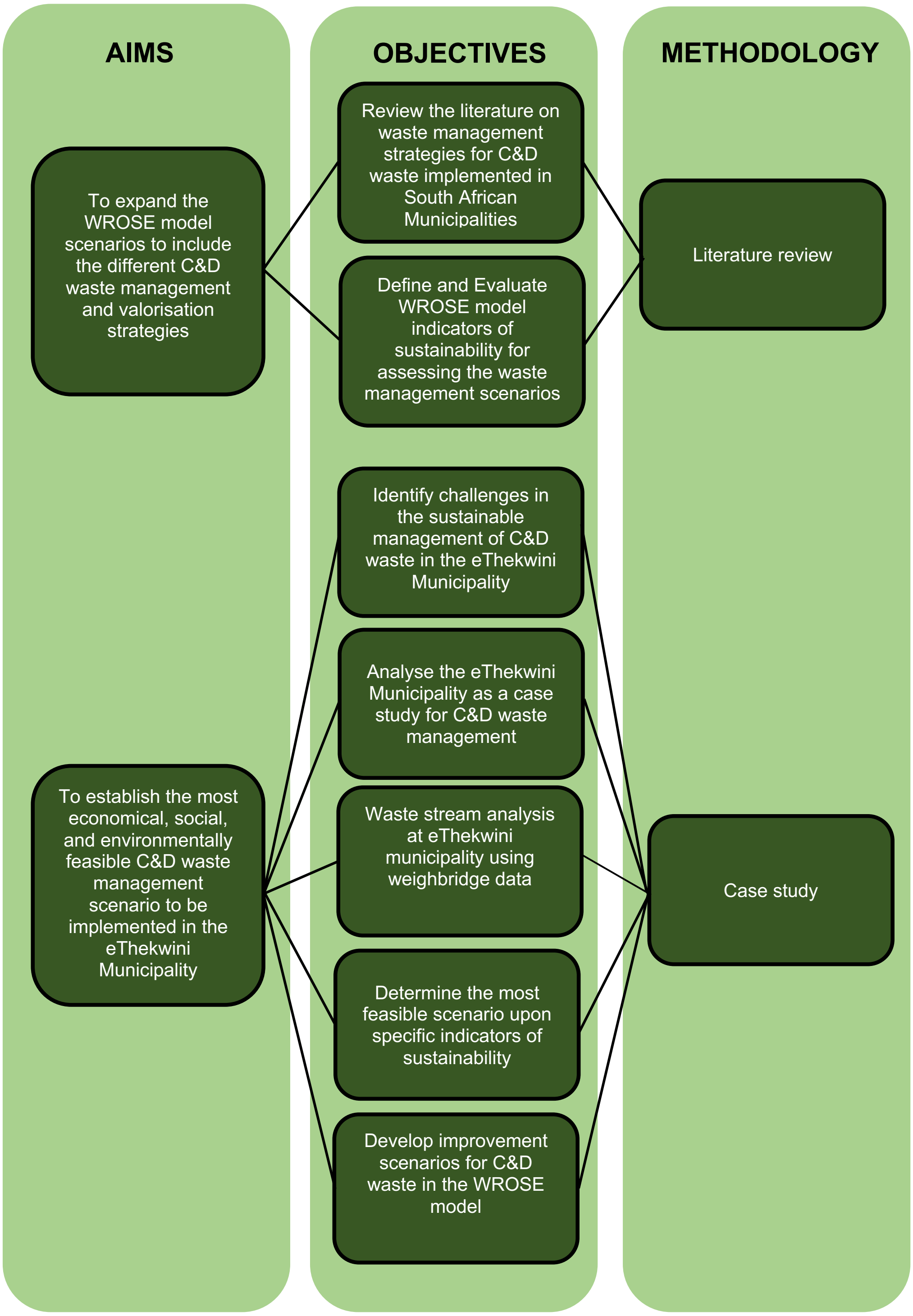

Figure 1.3 Framework of the connection of aims, objectives, and methodology

1.9 Research Framework

A flow chart of the complete research framework can be seen below in Figure 1.4. The figure shows that the research begins with a proposal outlining the various aims and objectives. The literature review showed the relevance of research, critically evaluating the waste management strategies that are practiced internationally and nationally. This was followed by a waste stream analysis of DSW's weighbridge data . This data was utilized in the creation of valorisation scenarios for C&D waste, which was placed in the WROSE model. The results are were analysed, and relevant recommendations are were made.

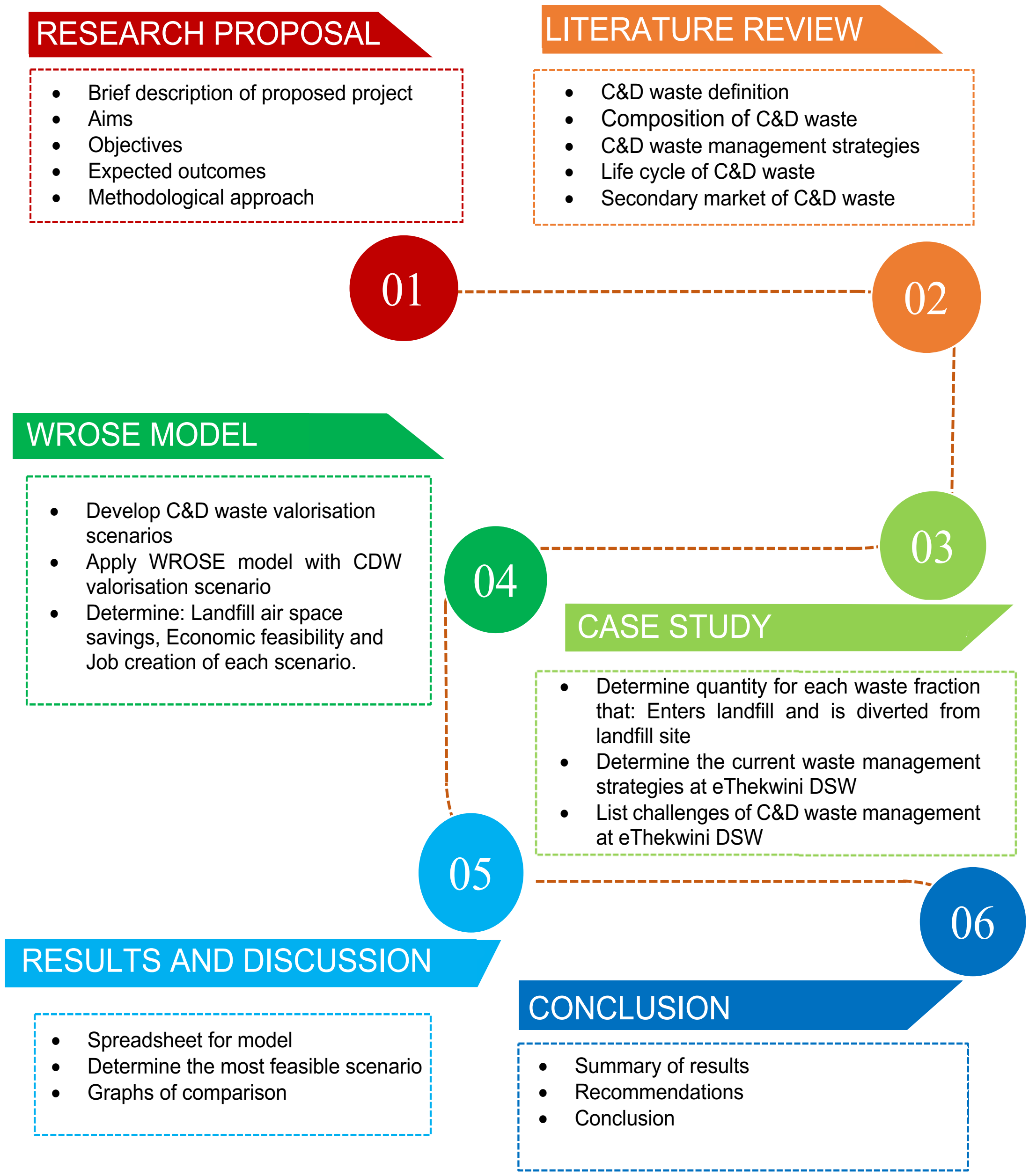

Figure 1.4 Research framework flowchart.

1.10 Structure of dissertation

The dissertation is structured in six chapters. The chapters are summarised as follows:

Chapter one: Introduction

Consists of the background and motivation of this study, including the research question and gaps. The various aims and objectives for this research project is explained in this chapter.

Chapter two: Literature review

Contains the literature review that discusses the broader aspects of waste such as definitions and classifications of waste as a resource. Then focusing on specifically construction and demolition waste management and greater detail about the construction and demolition waste management in South Africa, the drivers, challenges, and the status of the secondary market of construction and demolition waste.

Chapter three: Methodology

Consists of the methodology such as the different qualitative and quantitative approaches used to achieve the aims of this study.

Chapter four: Case study

Contains the case study of the eThekwini municipality DSW displaying a detailed knowledge such as a site overview, status quo and challenges of the various eThekwini municipality landfill sites. This chapter also shows Sandop Recovery World as a case study as this company specialises in recycling C&D waste, therefore an in-depth look on the status quo and processing of C&D at the Sandop Recovery World site.

Chapter five: Results and discussion

Consists of the results and discussion of the various data obtained throughout the study such as the analysis of weighbridge data and the results of WROSE Model.

Chapter six: Conclusions

Contains the conclusion of the study as well as the recommendations for future studies.

The next chapter, Literature review, explores the various waste management concepts with great detail to the management of C&D waste in South Africa and worldwide.

1.11 Chapter summary

This chapter presents the rationale of this research. The aim is to establish the most economical, social and environmentally feasible C&D waste management practices in the eThekwini municipality, South Africa. The WROSE model is intended to provide a decision-making process by evaluating economic, social and environmental indicators. Chapter 2 presents a literature review that provides further context to the study through previous research this study.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Introduction

This section presents the academic literature used for this research project. As such, it investigates concepts of Construction and Demolition waste and relevant definitions in section 2.2 and the composition and classifications of construction and demolition waste in 2.3. Source evaluation of this waste in section 2.4. A waste management overview of South Africa and an in-depth discussion of construction waste management in South Africa is discussed in sections 2.5 and 2.6.1, respectively. The drivers for sustainable construction and demolition waste management, shown in section 2.6.2. International and national sustainable construction and demolition waste management practices are discussed in section 2.6.3 and 2.6.4 respectively. with the life cycles of construction and demolition materials and WROSE model reviewed in sections 2.6.5 and 2.6.6, respectively. The secondary market for construction waste analysed in section 2.7, with the status quo of construction and demolition secondary market in South Africa in section 2.7.1 and Covid-19 impact on the construction and demolition industry in section 2.7.2

2.2 Construction and Demolition waste

Construction and Demolition waste is outlined as non-hazardous waste generated by all activities carried out during the construction, renovation, repair, and demolition of built structures or physical infrastructure. The resulting waste consists of concrete, bricks, masonry, ceramics, metals, plastic, paper, cardboard, gypsum drywall, timber, insulation, asphalt, glass, carpeting, roofing, site clearance, and sweepings and excavation materials as shown in Figure 2.1 (DEA, 2012).

Figure 2.1: C&D waste in a construction site (Source: (Pinatih, 2020)

According to the Waste Amendment Act (DEA, 2014, p.38), Construction waste is classified into two waste types:

Hazardous construction waste: (a) wastes from bituminous mixtures, coal tar, and tarred products (b) Discarded metals (including their alloys)(c) Waste soil (including excavated soil from contaminated sites), stones and dredging spoil (d) Wastes from insulation materials and asbestos-containing construction materials(e) Wastes from gypsum-based construction material(f) Wastes from other construction and demolition wastes.

Inert construction waste: (A) discarded concrete, bricks, tiles, and ceramics (B) discarded wood, glass, and plastic(c) Discarded metals(d) Discarded soil, stones, and dredging spoil(e) Other discarded building and demolition wastes

The Construction and Demolition wastes are considered waste due to the nature of the materials as it is broken and contaminated after the assorted construction and demolition activities. The perception is that it is of no or little value is shared among the industry. Due to Construction and Demotion waste being heterogeneous, therefore, there are various waste management approaches which are to be discussed further throughout this research.

2.3 Composition and classification of Construction and Demolition waste

Due to the variety of construction activities that occur, the composition of C&D depends on the type of construction on site e.g., road construction generates large amounts of excavated material, while concrete will be the main waste after demolishing a building. The heterogeneity of construction activities negatively impacts the validity compositions of waste and consequently, poor validity of waste management practices (Galvez-Martos et al., 2018). Figure 2.2 shows the general materials of C&D waste.

Figure 2.2: The general materials of C&D waste

Figure 2.3 shows the general composition of construction and demolition waste in South Africa. Concrete and masonry takes up the majority of composition followed by asphalt. Other C&D waste such as wood, metal, gypsum, plastic and miscellaneous materials contribute to a small amount of overall C&D waste generated.

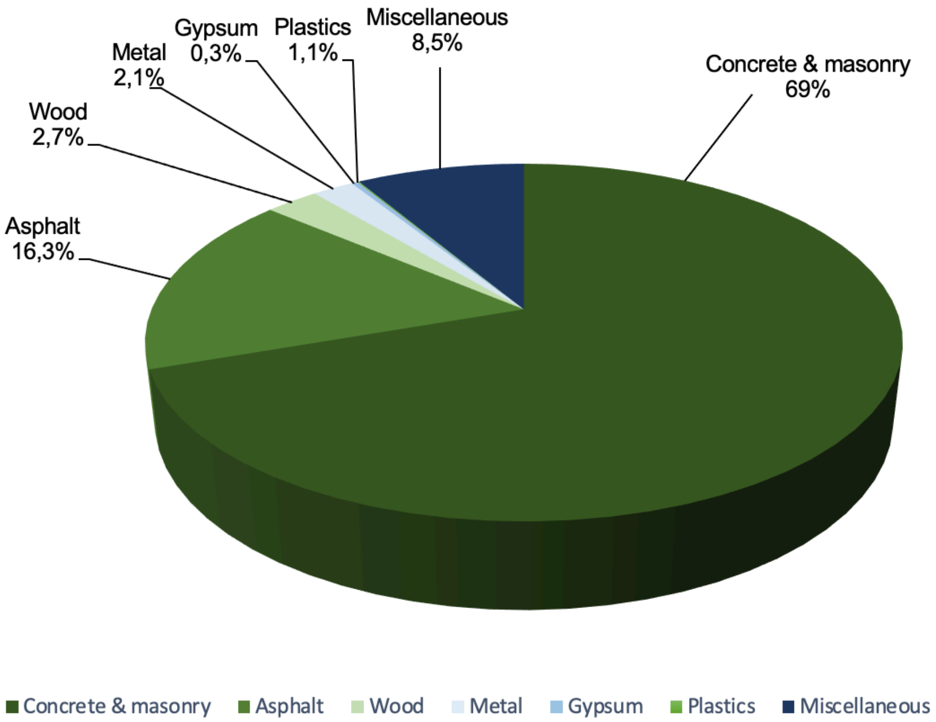

Figure 2.3: General composition of Construction and Demolition waste in South Africa (Source: DEA, 2018b)

2.4 Construction waste source evaluation

Waste is generated at each stage of the life cycle of construction. The life cycle of construction consists of four primary phases: design of construction, the realization of construction, occupation of construction, and demolition of construction. The design changes during the construction of the structure are one of the main causes of construction waste. Poor on-site management and planning significantly contribute to large volumes of C&D, leaving construction sites to enter landfills (Osmani and Villoria-Sáez, 2019).

2.5 Construction and Demolition waste management

Construction and Demolition waste management is a universal environmental issue that is of the utmost importance in the current context. (Akhtar and Sarmah, 2018) have researched 40 countries within six continents state that before 2012, the overall Construction and Demolition waste generated was 3.0 billion tonnes. These statistics are drastically inclining due to urbanization throughout the world, and this shows that an immense amount of energy can be preserved if proper C&D waste management is implemented, furthermore improving the economy. Figure 2.4 shows that C&D waste management practices vary throughout the globe due to being associated with high operating costs and relatively low added value from its recovery and recycling (Galvez-Martos et al., 2018). The size of the bubble represents the total amount of waste generated.

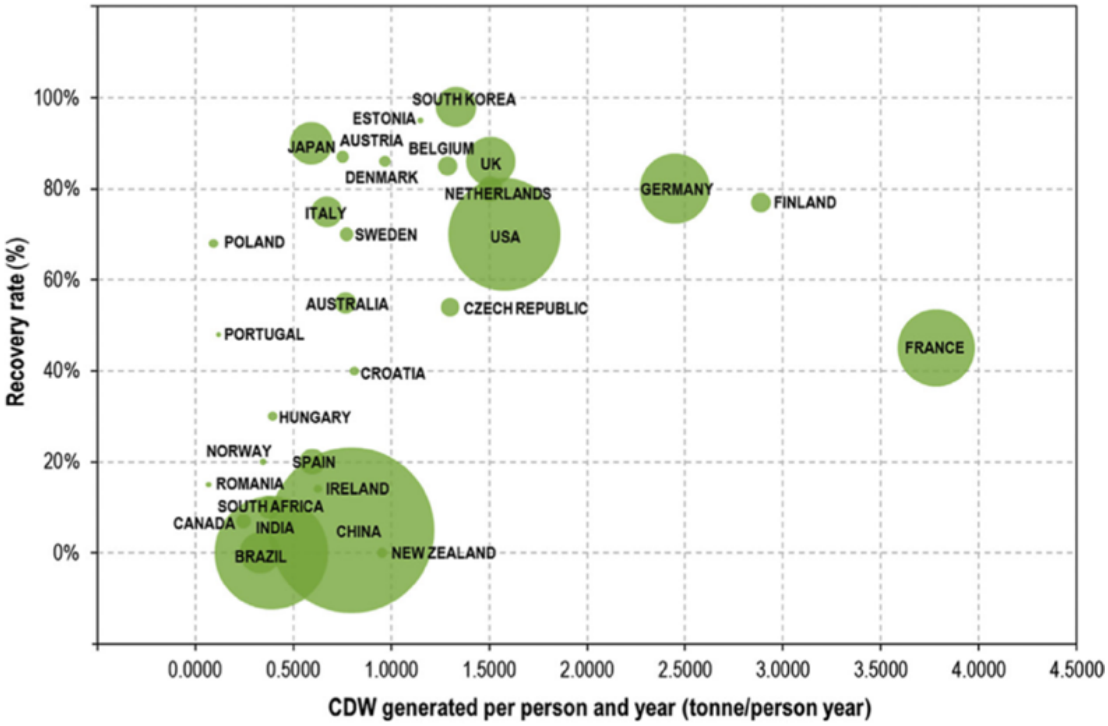

Figure 2.4: C&D recovery rate of various countries (Source: Galvez-Martos et al., 2018)

This figure also displays that many influential economies still need appropriate C&D recovery systems, hence a massive gathering of C&D waste in landfills.

The Figure 2.4 shows that many countries have sustainable C&D waste management practices , this may be due to the awarness of the benefits of using recycled C&D waste. Recycling C&D waste aids in reducing waste entering landfills and therefore extending the life of landfills as well as saving tipping fees. Reduction of transportation costs is possible as the waste can be recycled on site. New employment opportunities arise in a recycling activity that would not otherwise exist. There are a range of environmental and economic benefits in recycling C&D waste (IWMSA, 2018). The advantages of using recycled aggregates are shown in Figure 2.5.

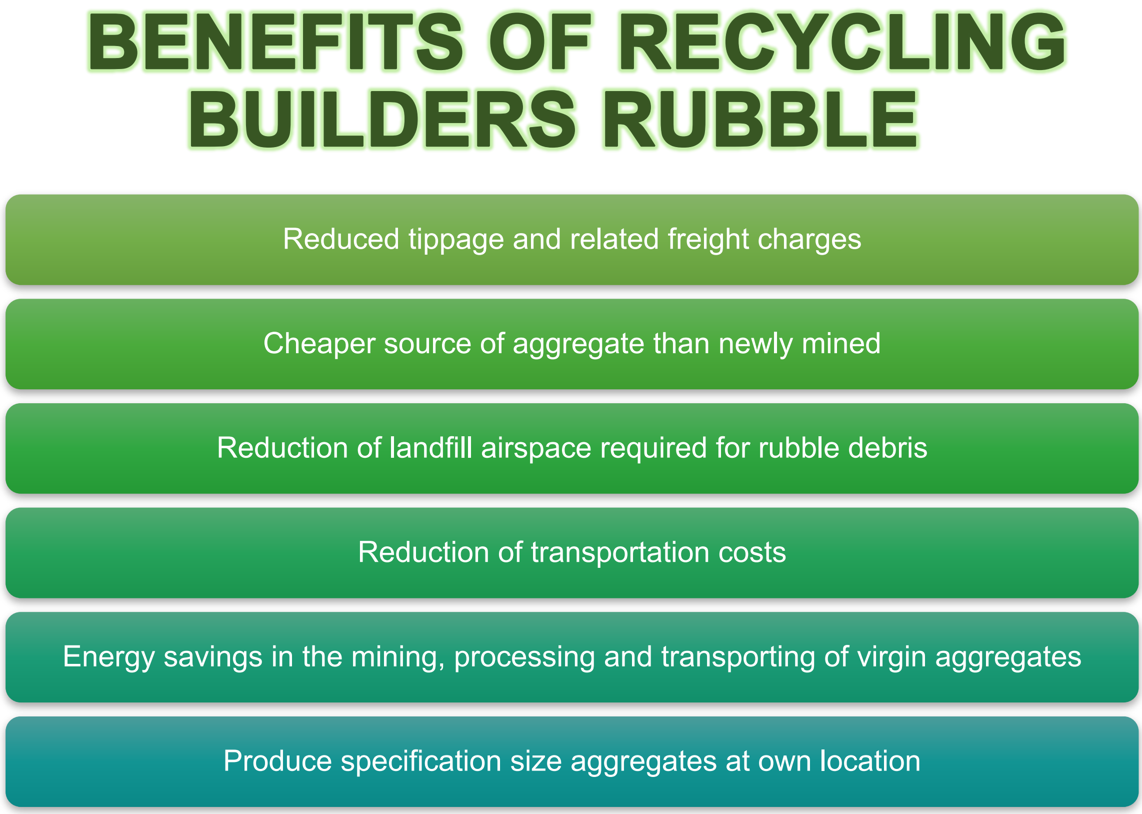

Figure 2.5: Benefits of using recycled aggregates(IWMSA, 2018).

There are numerous reuse options that have been identified. Builders rubble can be reycled through the use of a crusher. The products that are generated from this crushing are various sizes of aggregates. Recycled aggregates are utilzed in construction sector all over the world. Figure 2. 6 shows the current recycled aggregates being used in the market in South Africa.

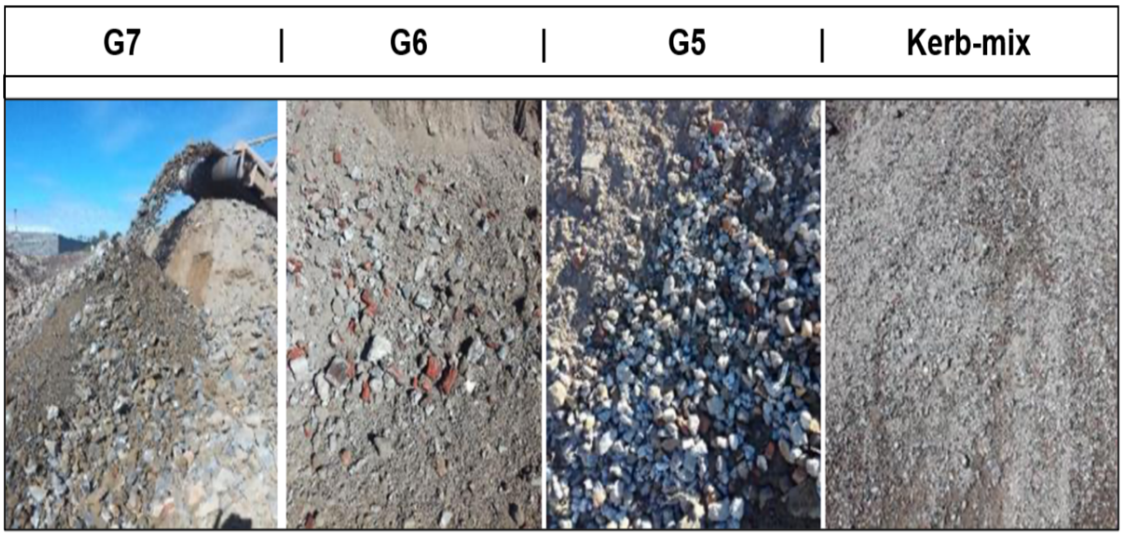

Figure 2.6 Current recycled aggregates used in the market in SA (IWMSA, 2018).

The applications of Construction and Demolition waste are:

Aggregate base course (road base)

One of the largest applications of recycled C&D waste is being used as the aggregate base course in road construction. G5 recycled aggregate consists of a top size of 53 mm down to fine dust. G5 is utilized below the G2 layer in the road construction industry. G7 is a low grade crushed product with a top size of 65mm down to dust. G7 is utilized at the bottom layer in road construction. This application is widely accepted for recycled concrete by Departments of Transportation across the world.

Soil Stabilization .

C&D waste that is recycled into aggregates can improve the soil stability issues. The load bearing capacity of sub grade can be changed through the addition of recycled aggerates which changes the water susceptibility of subgrade, hence increasing stability of the soil.

Pipe bedding

C&D waste that is recycled into aggregates has the ability to provide a firm foundation for laying underground utilities

Landscape materials

C&D waste that is recycled into aggregates can be utilised in various landscape applications such as paving stones, erosion structures, water features, stacked rock walls, retaining walls and other uses.

The applications of recycled builders rubble are illustrated in Figure 2.7

.

Figure 2.7: Application of recycled aggregates Source: (Hossain et al., 2020)

For C&D waste to be utilised, extensive tests and procedures must be completed due to the large variability of the C&D waste. Ensuring the quality of recycled builders rubble consists of the following procedures: There is to be constantly testing by SANAS approved labs are required to ensure minimum requirements are met. Separation or sorting at source, quality control process control implemented to ensure all grades of aggregates, separation before crushing and ensuring a quality control methodology once processed

2.6 Construction and Demolition waste management in South Africa

2.6.1 Overview of SA status quo

South Africa has taken a step towards a greener future through the implementation of Act No. 26 of 2014: National Environmental Management: Waste Amendment Act, 2014 (DEA, 2014), by committing to sustainable development whereby “balancing the broader economic and social challenges of a developing and unequal society while protecting environmental resources” (DEA, 2012, p.278). To achieve this aim of the Waste Amendment Act, in 2009, the National Waste Management Strategy (NWMS) is in operation. The objectives of the National Waste Amended Act are designed around the steps of the Waste Hierarchy, as the Waste Hierarchy is an international model for waste management prioritization, through a systematic method. The Waste Hierarchy is a tool that is used in the evaluation of processes that classifies methods of waste management in an environmentally sound manner. As methods that are resource and energy-demanding from the most preferable to the least preferred option. The waste hierarchy is displayed in the pyramid model as shown below in Figure 2.8

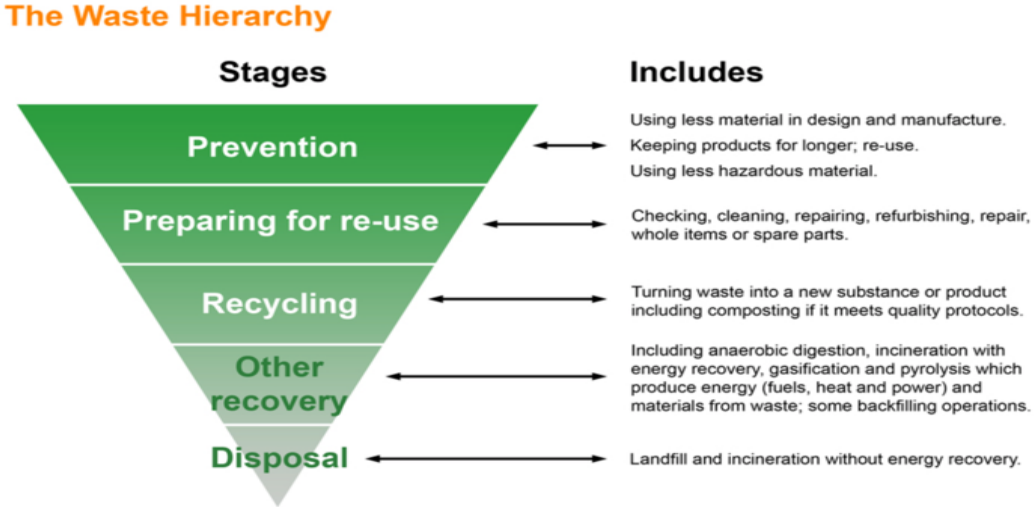

Figure 2.8: Waste Hierarchy Diagram (Source: Marlow, 2012*)*

Waste hierarchy methods are ranked according to what is optimum for the environment. Priority is given to the prevention and avoidance of waste. The design phase has the most significant influence on the amount of waste, as the amount of materials used for construction is specified. As by reducing the number of materials used, consequently reduces the potentially harmful waste produced during manufacturing and after use. Waste disposed of into landfills will be significantly reduced if all methods of the waste hierarchy are implemented effectively.

Although South Africa has implemented the practices of the waste hierarchy, the construction industry is a predominant contributor to the total waste produced in South Africa. According to the South African State of Waste Report (DEA, 2018b), the construction sector contributes 8,1 % to the overall waste produced. As South Africa advances economically, so does the level of urbanization rise, this consequently causes the rapid growth of the construction sector. Figure 2.9 shows the difference in general waste generation between 2011 and 2017 for the construction industry is 639% (South African State of Waste Report, 2018a). Hence the amount of construction and demolition waste has surged, showing that South Africa is in urgent need of efficient construction waste management.

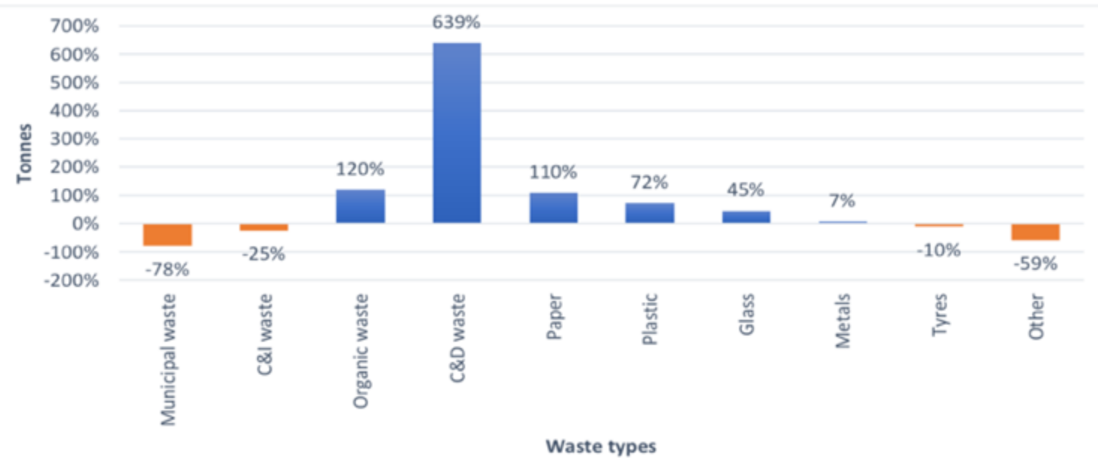

Figure 2.9: Difference in general waste generation between 2011 and 2017 (Source: DEA, 2018)

As the construction industry grows, developments in the proper management of this waste are implemented. According to the South African State of Waste Report (DEA, 2018b), 52% of construction and demolition waste, also known as GW30, was recycled/recovered in 2017. This is shown in Table 2.1. This shows the positive progress of Construction and Demolition waste management in South Africa. Hence further improvements will be accepted as the construction industry matures.

Table 2.1: General waste by management option in 2017 (DEA, 2018b)

Waste type		Generated	Recovered / Recycled	Landfilled	Percentage Recovered / Recycled
GW30	Construction and demolition waste	4 482 992	2 331 156	2 151 836	52%

As South Africa commences in implementing sustainable waste management practices, there are many drivers for recovery of construction and demolition waste.

2.6.2 Drivers for sustainable management in the construction sector

More than just keeping up to date with the trend of 'going green,' South Africa has many drivers for sustainable management in the construction sector. (Amaral et al., 2020) states that the construction industry has estimated to be the cause of 40% of the worldwide energy consumption. Global Alliance for Buildings and Construction, International Energy Agency and the United Nations Environment Programme (2019) states that in 2018, global buildings sector emissions increased to a record high of 9.7 GtCO2, rising by 2% from 2017. This increase in GHG emissions is due to the floor space of building expanding and the demand for electricity, which is still primarily fossil fuel-generated, as UN Environment and International Energy Agency (2017) states that 82% of final energy consumption in buildings was supplied by fossil fuels in 2015. Figure 2.10 shows the impact of the construction industry has on the environment.

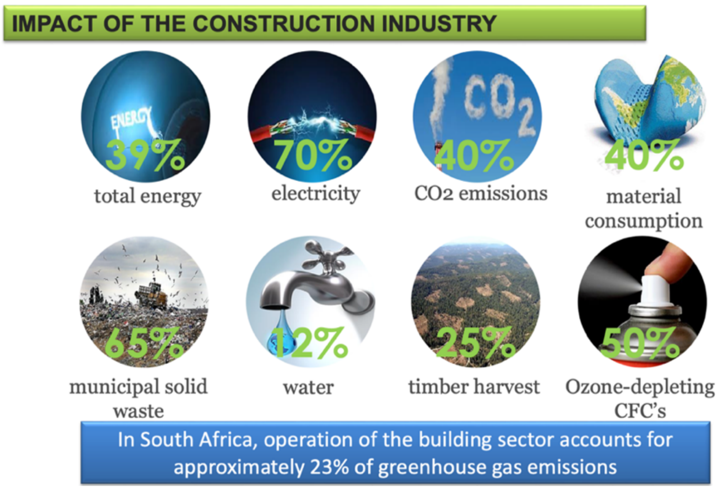

Figure 2.10: Impact of the construction industry has on the environment (Source: GreenCape, 2015).

The process of construction utilizes virgin materials that are at risk of becoming depleted due to the rapid surge in construction activities. This high amount of energy and greenhouse gas emissions are generated through the production and transportation of construction materials. Hence the considerable amount of savings if C&D waste extends after the end-of-life value and using it in new buildings or in secondary markets to substitute virgin materials.

The main driver for sustainable C&D waste management is one of South Africa's biggest crisis, insufficient airspace of landfills. Although C&D waste is inert, it is still dense and bulky, which occupies a significant amount of airspace (Hu et al., 2019). Figure 2.11 exhibits that South Africa's major cities have few years of landfill airspace remaining.

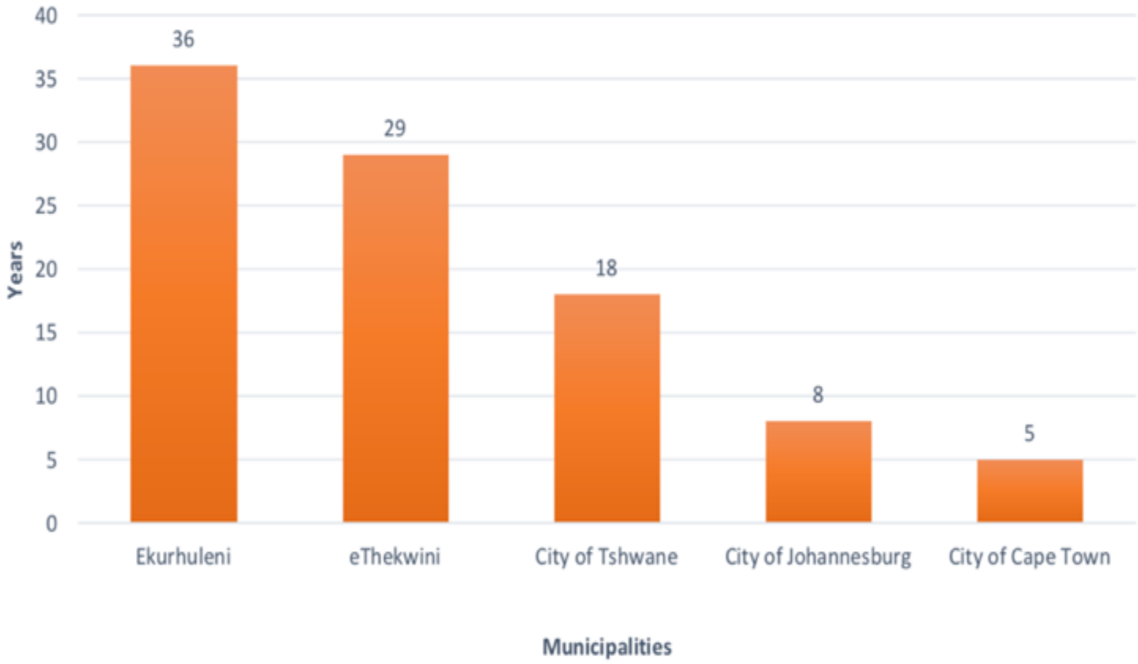

Figure 2.11: Estimated remaining landfill airspace of South Africa's largest municipalities (Source: DEA, 2018a).

Consequently, municipalities urgently need to redirect waste away from landfills. Hence construction waste is placing pressure on the limited landfill spaces available across South Africa. With the absence of alternative waste management strategies establish at landfills, when capacity is reached or forced the closure of landfills. This will have an immense impact on all levels of sustainability. Landfill workers will become unemployed. Greenhouse gases generated is increased due to the increased transport to other landfills. This, in turn, causes an increase in the cost of dumping, which leads to increased illegal dumping, hence increased levels of environmental pollution (Moodley et al., 2019). Construction wastes have become a pressing issue in many countries and have adverse effects on the environment, economy, and social aspects, several countries have developed sustainable waste management practices.

2.6.3 International sustainable C&D waste management practices.

The error to acknowledge the vast implications of economic development has cultivated a global environmental crisis induced by careless material resource management. Consequently, research is being performed throughout the world in an attempt to manage material resources efficiently and develop C&D waste prevention and minimization schemes (Osmani and Villoria-Sáez, 2019).

Source collection and separation, processing, and recovery and treatment are methods used throughout the world to recover and recycle construction and demolition waste. Figure 2.12 shows a summary of the different technologies for C&D recovery used in each stage of the process. Source separation ranges from manual to x-ray sensor; this is due to the budget, many countries have low levels of recovery due to insufficient funds. Other countries choose to use labour intensive options as there is social upliftment due to job creation.

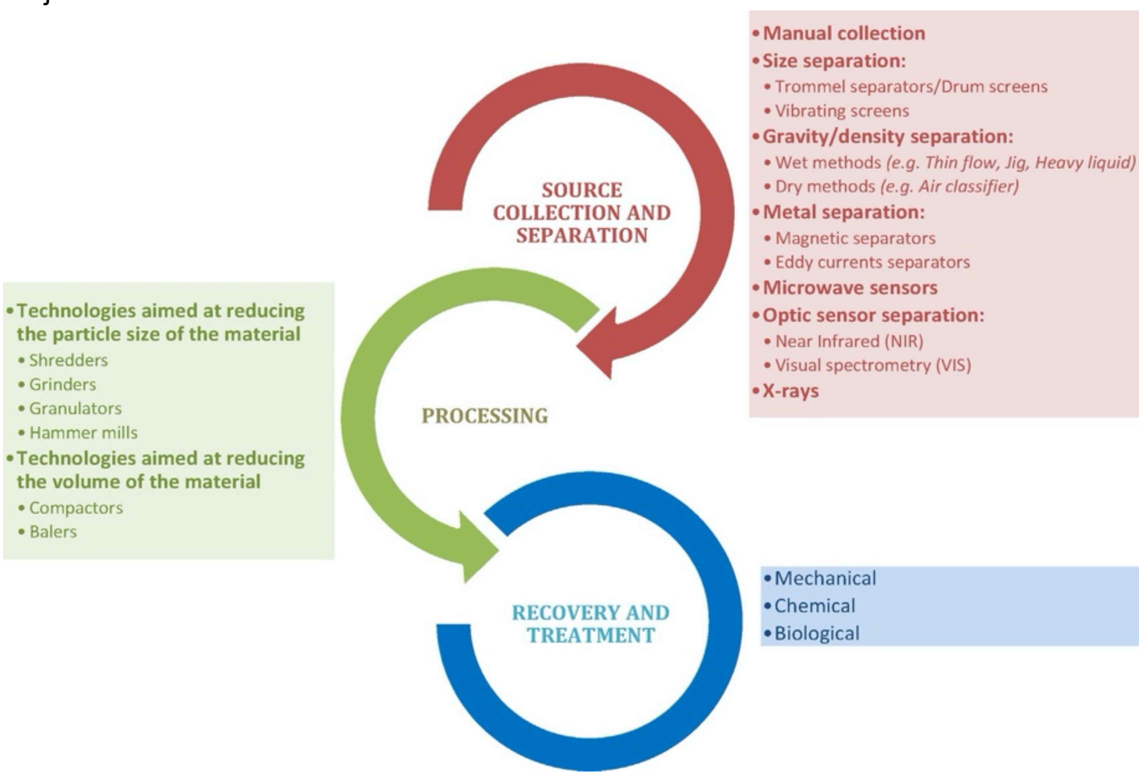

Figure 2.12: Construction and Demolition recycling and recovery technologies (Source: Osmani and Villoria-Sáez, 2019, p.377).

A study has researched construction and demolition waste generation in various countries within six continents. In Europe, Austria has a broad range of waste management systems as being a country with one of the highest collection and recycling rate in Europe. The waste management in Austria has contributed 1235 million euros to its economy while generating 14 779 jobs due to strict waste handling policies. In Denmark concrete waste dominates the construction industry generating approximately 5 million tons of concrete. This concrete waste is mainly used as recycled material in road construction. The Netherlands maintains a recycling rate of 80% and 10% for energy recovery through incineration of its C&D waste. In 2014 China produced the largest amount of C&D waste in the world with exceeding over 1.13 billion tonnes. This amount is due to the rapid growth in infrastructure due to the many fast growing companies in China. Whilst there are existing regulations in place in China, most if the C&D waste is landfilled and randomly dumped with recycling rates being a mere 5% (Huang et al., 2018). Japan has achieved a 90% recycling rate of its C&D waste, this is due to the change in regulations in 2002 which encouraged the use of recycled materials in the construction industry. Concrete, iron, wood and asphalt concrete was deemed compulsory to be recycled since 2002. This regulation added to the awareness and importance of recycling in Japan as well as reducing the amount of waste being disposed of into landfills (Akhtar and Sarmah, 2018).

The majority of C&D waste in these countries are that of concrete waste. The recycling rates varies from 5% to 90% in these countries due the variation of laws and regulations that govern the waste management of C&D waste. Recycling of C&D waste does not only benefit the environment but also the economy of the various countries.

As a developing country South Africa, the life cycles of construction and demolition utilize a few of the many technologies, there is potential to increase the recovery of construction and demolition waste.

2.6.4 National sustainable C&D waste management practices

There have been C&D waste management efforts made in South Africa. Organisations such as GreenCape, Atomic Demolishers and Sandop Recovery World are participating in the transitioning of a resilient green economy in the construction industry.

GreenCape is a non-profit organisation that drives the widespread adoption of economically viable green economy solutions from the Western Cape. GreenCape has been working closely with businesses, investors, academia and government to uncover the investment and employment potential of green technologies and services, and to assist in the shift to a green circular economy(GreenCape, 2016). GreenCape has many projects have been successfully completed with the reuse of construction and demolition waste. These projects are shown below:

Builders rubble was recycled for the project of a 2000 m^2 expansion of the Transnet City Deep container terminal in Johannesburg. This project required the resurfacing of the 144 000 m^2 facility, which generated 77 000 m^3 of concrete 'waste'. Recycling this waste and re-engineering to be used back into the revamp resulted in a 24% diversion from landfill. The savings were that of R10.8 million in virgin material cost savings (In 2017 the cost of a virgin G5 ranged between R120-160 per m^3) and R23 million worth of landfill gate fees were avoided (GreenCape, 2018a). Figure 2.13 shows the Transnet City Depp container terminal site in Johannesburg

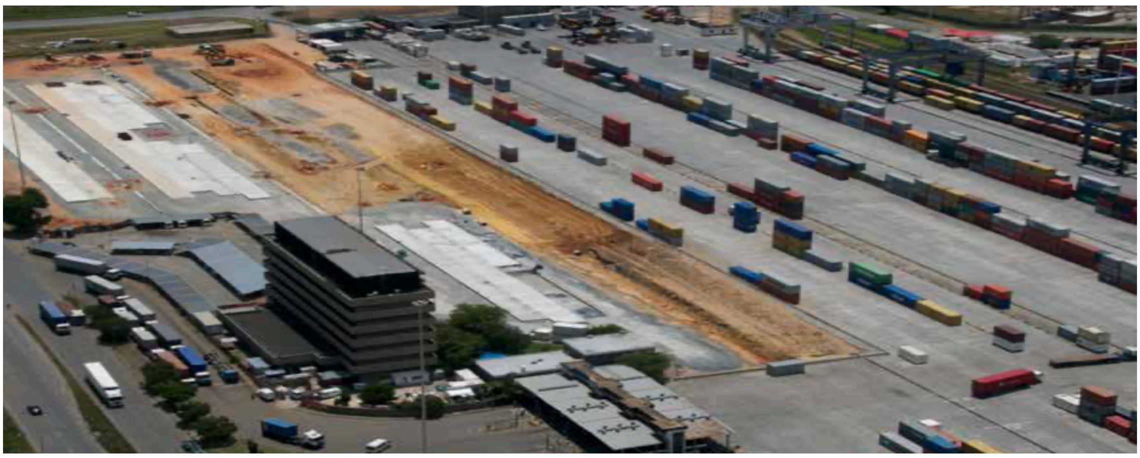

Figure 2.13: Transnet City Depp container terminal site in Johannesburg (Source: GreenCape, 2018a)

GreenCape assisted Woolworths in Montague Gardens, Cape Town, with the removal of their 15 hectare distribution centre. The demolition of this building generated 16 000 m3 of mixed waste. Through careful deconstruction allowing for the preservation of the highest material value of the rubble, all concrete, mortar and brick were processed and reused, with 90% of the demolition waste being reused. This resulted in a R585 000 savings in material costs (excluding transport) and R64 000 saved in fuel costs for transport of 'waste' to landfill. This project is an example of benefits of recycling C&D

waste (GreenCape, 2018b) . Figure 2.14 shows the Woolworths Distribution Centre site in Montague, Cape Town.

Figure 2.14: Woolworths Distribution Centre site in Montague Garden, Cape Town(Source: GreenCape, 2018b)

Iselula Crushing is a material hub in Blackheath, Cape Town that collaborates with GreenCape. This materials hub receives between 5 700 and 22 000 m^3 of builders' rubble per month from local demolition and construction companies. Insula Crushing diverts this material from landfill sites, resulting in a landfill air space saving worth R980 000 – R 3.8 million per month and providing 32 permanent staff. Materials such as Concrete, bricks and mortar are crushed and processed to produce aggregate materials namely G4, G5, G7, G9 and kerb mix to be utilized in new construction. Other C&D waste that is usually consider "contaminates" in aggregate producing businesses are also recovered and reused. Metal, Timber and PVC pipes are re-sold to the construction industry, this is usually to small businesses and community members (GreenCape, 2018c). Figure 2.15 shows Iselula Crushing in Blackheath, Cape Town

Figure 2.15 Iselula Crushing in Blackheath, Cape Town Source:(IselulaCrushing, 2019)

One of the largest C&D recycling companies in eThekwini is Sandop Recovery World. They are a licenced concrete and demolition waste processing operation and provides job opportunities to local community members. This company has participated in many recovery projects through eThekwini. Builders rubble is processed to produce aggregates of various sizes, therefore the aggregates are utilized in many ways. The aggregates are placed into the fractions of large pebbles, sand and even dust which is then re-introduced back into the construction industry (Sandop, 2020). Figure 2.16 shows Sandop Recovery World site in Cato Manor, Durban

Figure 2.16: Sandop Recovery World site in Cato Manor, Durban (Source: Sandop, 2020)

One of the most recent green projects in South Africa that has attracted much attention is the development of the City of Cape Town's new state-of-the-art Materials Recovery Facility (MRF) an existing operational landfill site that has incorporated construction waste into its design. The City of Cape Town and JG Afrika demonstrated their commitment to green and sustainable economic growth in the Western Cape by devising a means of re-using a landfill site for the development of a new Materials Recovery Facility. Figure 2.17 Shows the pre and post construction of the Coastal Park landfill sites new MRF.

Figure 2.17 Coastal Park project - pre and post construction (Source: SAICE, 2020)

This project has been awarded multiple prestigious awards at the Construction World's 2020 Best Project Awards. The project won in both the Consulting Engineers category and against stiff competition, including impressive renewable energy projects, in the AfriSam Innovation Award for Sustainable Construction category. At the South African Institution of Civil Engineering's (SAICE) National Awards 2020, this project was Highly Commended by the panel of judges in the Community-Based Project Awards and Technical Excellence Awards categories, respectively (SAICE, 2020). Figure 2.18 Shows the various awards this project has presented with.

Figure 2.18 Awards JG Afrika has received for the Coastal Park MRF project (Source: SAICE, 2020).

The Coastal Park landfill site had a 20m high, 450 000m3 builder's rubble deposit covered a large portion of the landfill site, with no available space to accommodate this waste. The transportation of this C&D to another landfill site would have been an additional cost of approximately R 65-million. The builders rubble was then utilized as a resource in the construction of the MRF. The builder's rubble was crushed, screened, and processed into an engineered fill product and used in the layer and bulk earthworks. Numerous test was conducted on the C&D stockpile. The results demonstrated that G5 quality material was able to be generated. The processed builder's rubble, with adequate treatment and the inclusion of certain additives was able to perform as a top soil included in the capping layers to cover the 5m-to 6m thick municipal solid waste deposit. Figure 2.19 Shows the contribution of the recycled builders rubble into design of the construction of the Coastal Park MRF.

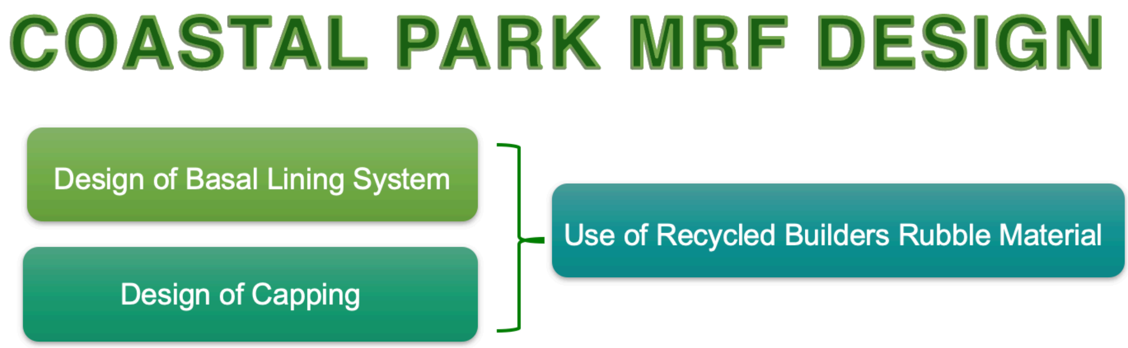

Figure 2.19 Builders Rubble contribution in construction of Coastal Park landfill site MRF

Through the recycling of construction and demolition waste projects in South Africa waste shows the benefits of proper waste management. These projects saved money on raw materials and landfill airspace and avoided greenhouse gas emissions associated with the extraction, processing and transport of virgin construction materials while creating job opportunities. The State of Waste report displays the in-depth look at the life cycles of construction and demolition waste in South Africa

2.6.5 Life cycles of construction and demolition waste in South African Municipalities

Throughout the imperfect life cycle of construction materials, there is a large amount of waste generated. (Raymonds Group Ltd, 1999) suggests that there are four different destination alternatives for C&D waste. This includes landfilling, incineration, re-use, and recycling of C&D waste.

According to the State of the Waste Report (DEA, 2018b), the re-use, recycling, and recovery of construction and demolition waste generation are not well recorded in South Africa. This is mainly because construction and demolition and re-use are typically separate at source e.g., intact bricks, wood, roof tiles, and glass. furthermore, C&D waste is generally used in landfills as cover materials. The following life cycles is a summary of waste management strategies in South African Municipalities and is not necessarily true for every Municipality in South Africa.

Crushing is most widely practice from recycling concrete masonry and demolition waste, with several mobile and permanent crushers operating in South Africa. The majority of the crushers are concentrated in metropolitan areas. The crushed aggregate is used as fill or in road sub-bases, similarly is typically milled and either in the pavement, aggregate base or subbase. Another use for RA is in the stormwater sector as this granular material is needed for drainage layers (Delaware, 2003). “RCA can be used to replace conventional natural aggregates fully. However, the replacement may be associated with the depreciation of concrete properties” (Yap et al., 2019, p.6). The life cycle for construction and demolition concrete, masonry, and asphalt waste at SA landfills shown in Figure 2.20.

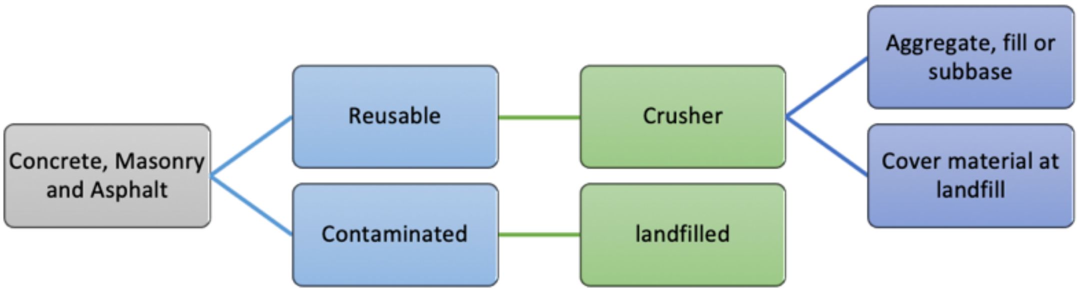

Figure 2.20: Life cycle for C&D Concrete, Masonry and Asphalt waste in SA landfills

In South Africa, waste wood from construction sites is typically re-used, whereas demolition wood is often landfill due to contamination. Of all materials in construction and demolition waste. Timber salvaged for new structural or material use; timber waste ground into mulch or compost (DEA, 2018b). Wood can be used in non-structural construction as wood-chip concrete does not have sufficient strength to support structural construction. Wood-chip concrete is formed by the voids of the compacted wood chip being injected by cement grout (Delaware, 2003). The life cycle for construction and demolition wood waste at SA landfills shown in Figure 2.21.

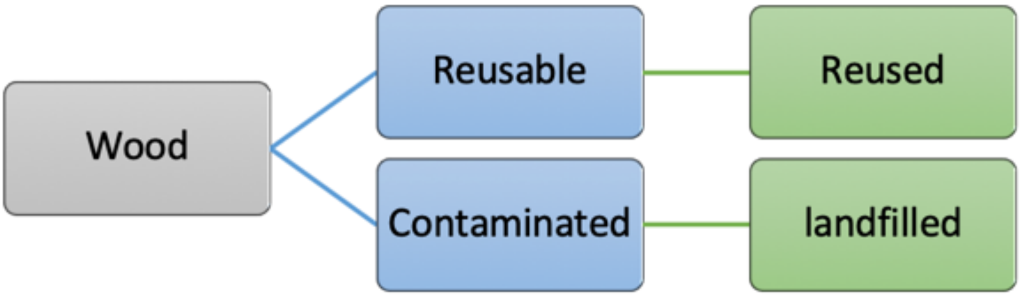

Figure 2.21: The life cycle of C&D wood waste in SA in landfills

Metals generally have the highest recycling rates. Steel, aluminium, and other metals for re-use in the manufacture of new metal products. The management of Metal waste on construction sites is that the steel is separated from the other wastes as it will be collected to be sold as scrap metal to recycling facilities. The demand for re-using old metal as reinforcement bars has grown to such a high extent that employees are paid to straighten twisted metals bars to use for reinforcement (Delaware, 2003). The life cycle for construction and demolition metal waste at SA landfills shown in Figure 2.22.

Figure 2.22: The life cycle of C&D metal waste in SA landfills

Gypsum is generally contained in plasterboard, decorative plaster, building plaster, plaster blocks, gypsum-based self-levelling screeds, and gypsum fibreboards. While there is some capacity in SA to recycle gypsum plasterboard, gypsum is landfilled. The life cycle for construction and demolition gypsum waste at SA landfills shown in Figure 2.23.

Figure 2.23:Life cycle of C&D gypsum waste in SA landfills

It is assumed that the residual waste that has not been recycled or recovered is disposed of to landfill. While there are some losses due, to for example, littering, these are assumed to be insignificant. In South Africa, a model was created to maximise the resources and materials available with responsible waste management strategies called the WROSE model (Kissoon and Trois, 2018).

2.6.6 The WROSE Model

The Waste Resource Optimisation Scenario Evaluation (WROSE) decision-making tool is centred around the concept of zero waste (Kissoon and Trois, 2018). That aims to combat the various waste management key issues in South Africa. These fundamental issues include the challenge of trying to attain high-quality service delivery with a lack of high quality resources, inadequate environmental control systems, limited data on various waste streams and their GHG emissions indicators, and the insufficient environmental and waste awareness of the society and industry (Trois and Jagath, 2011; Kissoon et al, 2018; Kissoon and Trois, 2019;). Figure 2.24 shows the WROSE Model inputs and outputs.

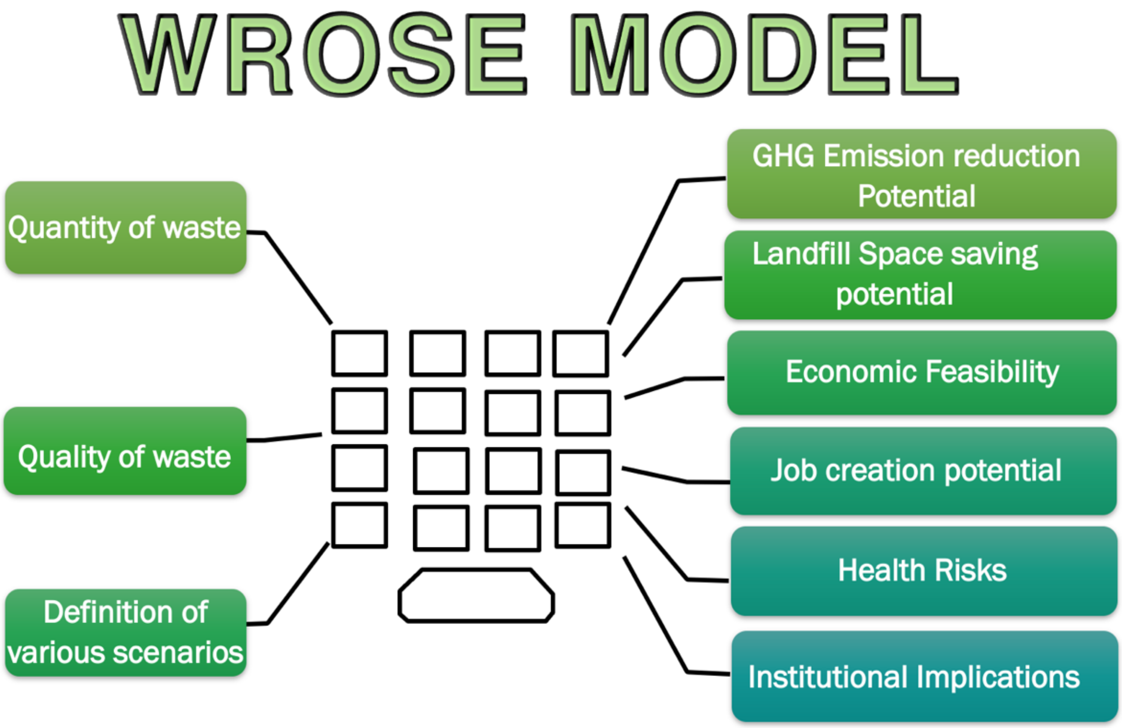

Figure 2.24: Inputs and outputs of WROSE Model

The WROSE model is a waste management decision making tool that provides a methodology for municipalities to evaluate and optimise their waste management strategies to achieve a fully integrated system. This optimization is done by establishing various scenarios that waste can follow and, most importantly, the impacts of each scenario. These impacts include environmental, economic, socio-economic, and Institutional indicators (Kissoon and Trois, 2018).

The WROSE model uses a Microsoft Excel spreadsheet interface. The quantity of waste, quality of waste, and definition of various scenarios are to be input into the model generating comprehensive data of the different indicators. The user enters input values of the amount of waste disposed or diverted by each strategy (in metric tons) for the scenario being evaluated (Jagath, 2010). The input screen of the WROSE Model is shown in Figure 2.25

	A	B	C	D	E	F
1	WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL					
2	W.R.O.S.E					
3	WASTE MATERIAL OR	Quantity of Waste Disposed/treated/diverted by (tons):				
4	WASTE FRACTION	LANDFILL	LANDFILL	RECYCLING	ANAEROBIC	AEROBIC
5		DISPOSAL	GAS REC		DIGESTION	COMPOSTING
6	Newspaper	5453				
7	General mixed paper (CMW)	7234				
8	Scrap Boxes & Cardboard (K4)	11402				
9	Low density polyethylene (LDPE)	2450				
10	High density polyethylene (HDPE)	1401				
11	Polyethylene-terephthalate (PET)	2037				
12	Polypropylene (PP)	1613				
13	Polyvinyl Chloride (PVC)	8				
14	Polystyrene (PS)	1101				
15	Glass	6861				
16	Steel Cans/Tins	4245				
17	Aluminium Cans	547				
18	Biogenic Food Waste	36608				
19	Garden Refuse: Green	637				
20	Garden Refuse: Wood	46				
21	Other	32287				
22	Total Waste Diverted/Disposed	113930	0	0	0	0

User enters waste fraction quantities to be diverted or disposed of by each strategy.

Figure 2.25 WROSE Model input screen (Jagath, 2010)

Once the inputs are placed into the model, the various outputs (GHG Emission Reduction, Landfill Space Savings, Economic Feasibility, Job creation potential, Health risks, Institutional implications) are then automatically generated as shown in Figure 2.26 in the output screen.

	A	B	C	D	E	F
1	WASTE & RESOURCE OPTIMISATION STRATEGY EVALUATION MODEL					
2	W.R.O.S.E					
3	WASTE MATERIAL OR	Greenhouse Gas Emissions/Reductions				
4	WASTE FRACTION	LANDFILL	LANDFILL	RECYCLING	ANAEROBIC	AEROBIC
5		DISPOSAL	GAS REC		DIGESTION	COMPOSTING
6	Newspaper	0	-7092.87	0	-	-
7	General mixed paper (CMW)	0	-3747.84	0	-	-
8	Scrap Boxes & Cardboard (K4)	0	-5781.53	0	-	-
9	Low density polyethylene (LDPE)	0	108.03	0	-	-
10	High density polyethylene (HDPE)	0	61.77	0	-	-
11	Polyethylene-terephthalate (PET)	0	89.82	0	-	-
12	Polypropylene (PP)	0	71.12	0	-	-
13	Polyvinyl Chloride (PVC)	0	0.35	0	-	-
14	Polystyrene (PS)	0	48.55	0	-	-
15	Glass	0	302.52	0	-	-
16	Steel Cans/Tins	0	187.17	0	-	-
17	Aluminium Cans	0	24.12	0	-	-
18	Biogenic Food Waste	0	6456.55	-	0	0
19	Garden Refuse: Green	0	-435.35	-	-	0
20	Garden Refuse: Wood	0	-47.16	-	-	0
21	Other	0	1423.61	0	-	-
22						
23	Strategy GHG Emissions/	0	-8331.14	0	0	0
24	Reductions (MTCO₂eq)					
25	Total GHG Emissions/Reductions (MTCO2eq)					-8331.14

Figure 2.26 WROSE Model output screen (Jagath, 2010)

The outputs of the model were specifically chosen to provide an economical, environmental, socio-economic analysis of the various waste management practices. Therefore economic, environmental and socio- economic indicators were utilised in the WROSE model.

The environmental indicators which display the GHG Emission Reduction Potential and Landfill Space saving potential. These are vital indicators to waste management as a significant amount of GHG emissions are generated at each step of the life cycle process of waste. Landfill space saving is essential to recognise due to the limited airspace available in South Africa.

Economic indicators that exhibit the economic feasibility of each scenario, the cost and revenue are to be displayed as there is a possibility of additional income due to recycling and recovering waste. The economic evaluation is essential as it is often the deciding factor with regards to choosing a scenario.

Socio-economic indicators which present the job creation potential and health risks of workers. This indicator is crucial as one of South Africa's biggest challenges is unemployment, which now stands at 30.1%, according to SA Stats. Hence by indicating job potential, municipalities and companies can attract investors, thereby growing the economy. The health risk of workers is an imperative indicator as one of the basic South African human rights is to that of a safe environment. Direct and indirect health risks of workers occur at every stage in the waste management process, from the point where workers handle waste in the enterprises for collection or recycling to the point of ultimate disposal (Jerie, 2016). Municipalities and companies have to meet extensive criteria to ensure the safety of workers; therefore, the presentation of these socio-economic indicators are invaluable.

The institutional indicator presents the institutional implications. This is formulated into three main categories: Environmental, energy, financial and administrative legislation. Waste laws regulate the management of waste to protect the health of people as well as the environment (plants, animals, land, air, water etc.). The WROSE model shows these licenses required by the related legislation for the various scenarios. This is done to ensure all waste management practices adhere to the numerous legislation. The function of these comprehensive indicators assists in decision making, which has the highest environmental benefits, lower costs, higher job creation potential, minimal health risks, and institutional red tape.

(Reddy, 2016) conducted an indicator assessment of the WROSE Model indicators. This assessment was completed by Waste management experts, Dr Alessio Cibati and Dr Elena Friedrich. The various indicators were ranked from 1 to 3 according to a corresponding selection criteria, with 3 being the best for that criteria. The selection criteria is that of the following categories: relevant, meaningful, comprehensive, scalable, practical and intergenerational. The selection criteria is explained below in Figure 2.27.

Figure 2.27 Indicator evaluation selection criteria explanation (Reddy, 2016)

Figure 2.28 shows the WROSE Model indicator evaluation. Figure 2.28 reveals that Landfill Space Savings has the highest rating in the environmental indicator section. Landfill Space Savings is shown as a crucial indicator for when evaluating the impact of waste management strategies.

The economic indicator section reveals that Capital cost, Operating cost as and Income and Savings showed relatively similar ratings. The financial aspect of waste management is of high importance in order to attract investors and expand the circular economy.

The social indicator sections presents Job Creation and cleanliness as the highest rated indicators. Job Creation is also needed in order to attract investors to fund various waste management projects.

This indicator evaluation displayed in Figure 2.28 shows the relevance of the chosen indicators used for this research. The Figure 2.28 indicates that the WROSE Model indicators, Landfill space savings, Operating cost and Job creation are all acknowledged by waste management experts to be most relevant, meaningful, comprehensive, scable,practicle and intergenerational out of all the corresponding environmental, economic and social indicators.

Environmental indicators	relevent	meaningful	comprehensive	transferable/Scalable/consistant	practicle/actionable	intergenerational/durable	SUM
Global warming potential (MTCO2eq)	2.5	2	3	2.5	2	3	15
Landfill space saving	3	3	3	3	2.5	3	17.5
Terrestrial Acidification Potential (SO2)	2	2	2	2	2	2	12
Eutrophication Potential (Nox)	2.5	2.5	2	2	2	2.5	13.5
Ozone Depletion Potential (CFC)	2.5	1.5	2	2	2	2	12
Waste diversion rate	2.5	2.5	2.5	2.5	2.5	3	15.5
Water consumed	2	1.5	1.5	1.5	2.5	2.5	11.5
Energy consumed	2	1.5	2	1.5	2.5	2.5	12
Economic indicators							
Capital costs	3	3	3	3	3	3	18
Operating cost	3	3	3	3	3	2.5	17.5
Income/Savings	3	3	2.5	3	2.5	2.5	16.5
Financial sustainablity	3	3	1.5	2.5	2.5	1.5	14
Sensitivity to variables	2	3	1.5	2.5	1.5	2	12.5
Social indicators							
Jobs creation	3	3	3	2	1.5	3	15.5
Noise generation	1.5	1.5	1.5	2.5	2.5	2.5	12
Public acceptance/Social perception	3	2.5	3	1.5	1.5	1.5	13
Cleanliness/Smell	3	3	1.5	2.5	3	2.5	15.5
Social participation	2	1.5	1.5	1	1	1	8

Figure 2.28: WROSE Model indicator evaluation (Source: Reddy, 2016)

The indicators are used in the analysis of each scenario present in the WROSE Model. Currently Figure 2.29 shows the current scenarios that are available in the WROSE Model that are the mostly used scenarios for municipalities based on input of unsorted municipal solid waste. There is an identified gap which is that there is no specific scenarios for construction and demotion waste, which this research aims to fill that gap.

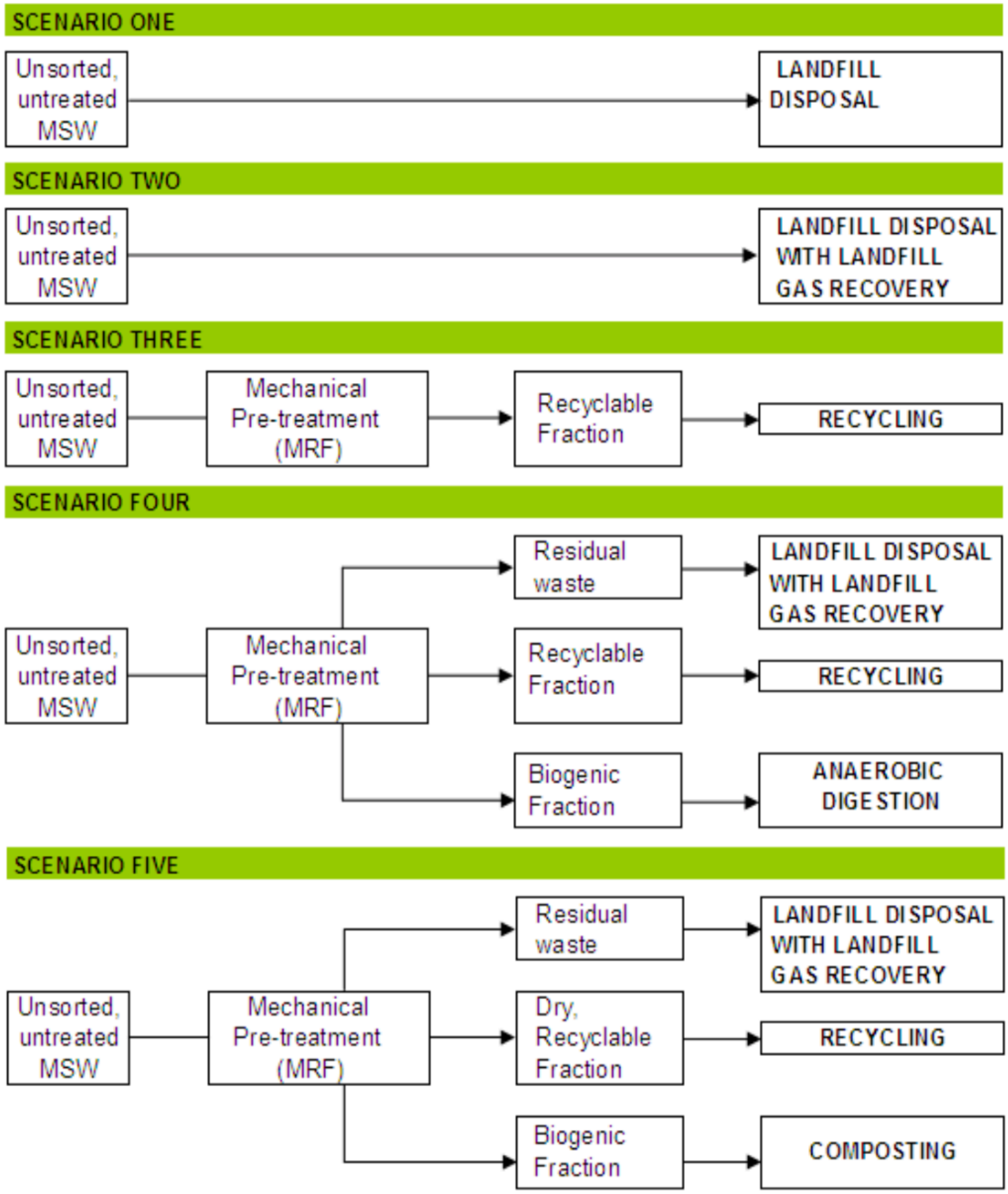

Figure 2.29: WROSE Model scenarios (Source: Kissoon and Trois, 2019)

The WROSE model is able to be a stimulus of the secondary market by showing the economic, environmental, and social benefits of the recovery of construction and demolition waste.

2.7 Analysis of the secondary market for construction and demolition waste in SA

2.7.1 Status quo of construction and demolition secondary market in SA

As the concept of a circular economy is gaining popularity throughout the world, the maturity of the secondary market becomes key in achieving this concept.

The circular economy is defined as "A concept in which growth and prosperity are decoupled from natural resource consumption and ecosystem degradation. By refraining from throwing away used products, components, and materials, instead of re-routing them into the right value chains, we can create a society with a healthy economy, inspired on and in balance with nature" (Vos et al., 2016).

Vos et al. (2016) suggest that the circular economy model discerns the following technical cycles: Maintaining product, Re-using/redistributing (used) product, Upgrading/ remanufacturing products and Recycling products. Figure 2.30 illustrates the circular economy.

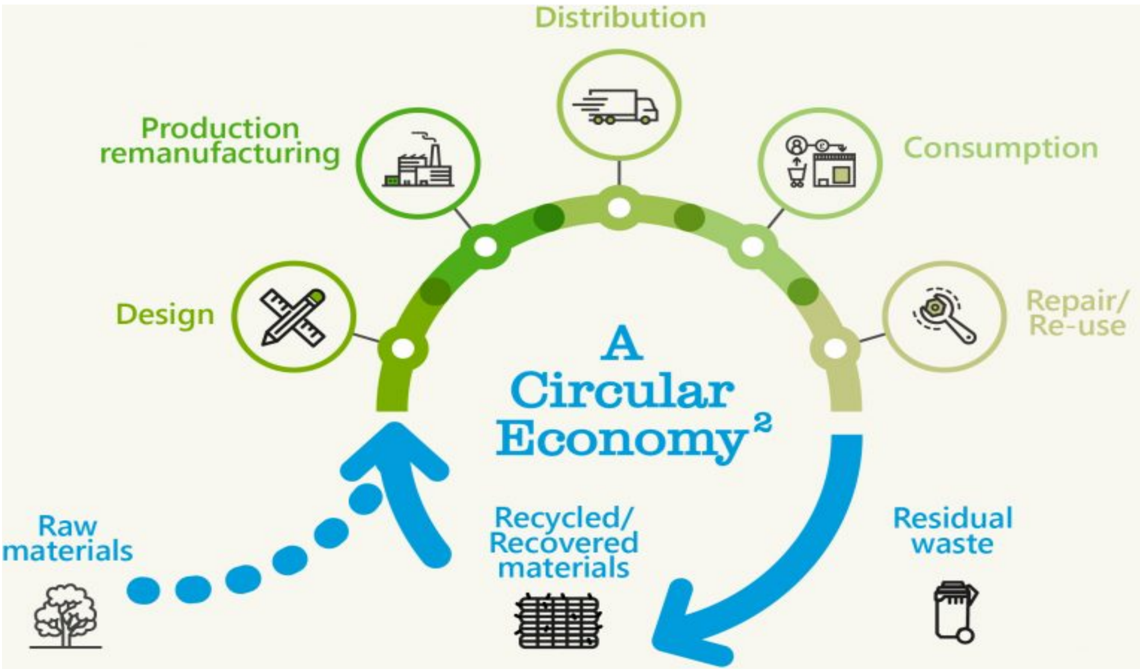

Figure 2.30: The Circular Economy (Source:(managementors, 2020)

Despite the progression of recycling construction waste, the construction sector has been slow to commit to establishing the secondary market for construction waste. The secondary market consists of suppliers, industries, secondary material end consumers, and products created from recycled construction and demolition waste (Macozoma, 2002).

In South Africa, there is a slow but steady progression in the waste economy as, according to the DEA (2017), the waste economy granted approximately R24.3 billion to the South African GDP in 2016. This resulted in the provision of 36 000 formal jobs and 80 000 informal jobs. It has been estimated that waste economy could increase by a further R11.5 billion per year by 2023, therefore, removing 20 million tonnes of waste (GreenCape, 2018). "The DEAs' overall target is to increase waste diverted from landfill from an estimated 13% (14 million tonnes) in 2016 to 25%1 (29 million tonnes) by 2023; hence greater business and job creation benefits are expected" (GreenCape, 2018, p.1)

Various opportunities exist for the secondary construction waste industry to grow. The opportunities include the sorting and sale of builder's rubble. The drivers of these opportunities are the increase of construction and demolition companies, the rising cost of landfill fees and virgin material, the increase in awareness of cost-saving of this alternative, and the increased regulations regarding construction waste (GreenCape, 2018).

The secondary market for construction waste has not yet reached full potential; this may be due to the lack of knowledge and confidence in secondary materials. Other market constraints, according to (Delaware, 2003) include:

- Inexpensive cost of virgin materials

There is a lucrative competitive market of primary materials that exist in South Africa. Consequently, the price of virgin materials is decreased to ensure that companies survive. This lowered price poses a threat to recycling plants as such prices cannot be beaten by the recycling plants. Hence a barrier in the establishment of a secondary market for construction waste.

- Expensive cost for recycling plants.

Capital needed to establish a recycling plant is high. Investors lack confidence in the stability of the secondary market hence the insufficient amount of capital for a recycling plant.

- Environmental risks

Dust and noise pollution is the by-product of the process of recycling construction and demolition waste. Due to these concerns recycling of waste on-site and in residential areas is not approved. For this reason, recycling of materials is discouraged due to the high costs of transportation of waste to recycling plants.

- Lack of confidence in performance of recycled materials

One of the main reasons that recycled waste material is underused is because the standards and specification of recycled waste material are undermined. Contractors, investors, designers, and consumers have the perception of secondary materials being inferior as compared to virgin materials.

- Uncertain supply and demand of materials

It is challenging for recyclers to ensure a steady supply of recyclable materials to meet the demand as recycling of construction waste depends on the construction activities within a certain area. Recyclers cannot guarantee construction activities within an area and hence cannot guarantee the supply of construction waste.

Another constraint in the construction and demolition industry is the arrival of the COVID-19 pandemics.

2.7.2 Covid-19 impact on construction and demolition industry

The South African construction industry is under immense pressure due to shortened margins and rising costs, especially due to limited operations as a result of the Covid-19 lockdown. While detailed planning for new construction projects is fairly common, the same level of care is often not applied to the demolition phases. “The expectation is to conclude demolition quickly and cheaply, without much regard for the end use of the demolished materials. Achieving a fully-compliant site is perceived as an ideal that can only be achieved at a high cost. However, these certifications are possible with a well-planned and carefully thought-out approach,” highlights Jet Demolition Contracts Manager Kate Bester (EngineerIT, 2020). This increase of C&D waste to enter landfill sites shows that municipalities are in dire need of safe, efficient waste management practices, as well as paying special attention to the health risks involved in waste management. Studies have shown that the coronavirus may last a plastics, wood, stainless steel for up to five days (WHO, 2020). Consequently, municipalities have to implement safety mechanisms to ensure the safety of staff and the environment.

2.8 Chapter Summary

This chapter discussed the various aspects of waste management of construction and demolition waste. Detailing the definitions and classifications of construction and demolition waste, evaluation of source of this waste as well as the different waste management strategies used nationally and internationally. This chapter also reviewed the status quo, drivers, life cycles and the secondary market of construction and demolition waste in South Africa. Although there are many waste management strategies that are used all over the world South Africa still lags behind. Therefore, this research aims to improve the waste management strategies in eThekwini. The next chapter displays the methodology used to achieve the aim of this research.

CHAPTER 3

3. METHODOLOGY

3.1 Introduction

This chapter outlines the following detailed experimental methodology followed in this research dissertation. The methodology used in this chapter was used to achieve the aims and objectives set in the first chapter. This research requires a case study of eThekwini Municipality where the investigation of the waste management at the landfill sites is to be executed. Sandop Recovery World is also part of the case study, where the investigation of the company operations. The WROSE Model was used to calculate the landfill airspace savings, social upliftment and cost of the various waste management practices.

3.2 Methodological approach

This research dissertation comprises of the following two approaches of a theoretical approach and a case study approach.

3.2.1 Theoretical approach

A literature review allowed for the critical analysis of determining the extent to which the management of C&D waste and the various developments that have been made to contribute to the circular economy nationally and internationally. Therefore identifying the research gaps present.

3.2.2 Case study approach

eThekwini Municipality landfills and Sandop Recovery World are the case study involved in this research. The eThekwini municipality granted the examination of the C&D waste management of their landfill sites. Sandop Recovery world provided information about waste management strategies. The case study enabled for the in-depth understanding of the complex problems of C&D waste management in a real-life context.

3.3 Research Method

The theoretical and case study approaches allowed for all aspects of the research topic to be covered. To achieve the aims of this research, which is to determine the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in eThekwini Municipality landfill, the following methodology was followed.

3.3.1 Research proposal

A research proposal was executed to clearly define the research problem and create steps towards achieving the desired results of this research. The research proposal consists of aims, objectives working schedule, and anticipated results to ensure that this research will be well structured.

3.3.2 Literature review

The academic literature is used to examine the assorted concepts of construction and demolition waste, including waste composition, the life cycles of the various wastes and the challenges, and the different strategies of waste management that are applied worldwide as well as in South Africa as this research involves developing the WROSE model, therefore evaluation of the WROSE model indicators. The sources for the literature review were that of peer-reviewed journals, articles, and past dissertations found by using the search portal Research Gate. These sources are referenced throughout the dissertation and appear in the reference section.

3.3.3 Selection of case study

eThekwini municipality was the chosen case study as it is the third largest municipality in South Africa, therefore the waste generated in this municipality is representative of South Africa. Recycling is one of the main waste management strategies for construction and demolition waste. Therefore, Sandop Recovery World was chosen as a case study as well as it is one of the largest construction and demolition waste recycling facilities available in eThekwini. Sandop recovery world's operations were used as a reference to set construction and demolition strategies for the eThekwini municipality.

3.3.4 Data collection

Zoom meeting as well as site visits to the eThekwini municipality's DSW head office took place whereby data was collected about the construction and demolition waste stream that enters of the landfill site in the eThekwini municipality. These interviews eThekwini municipality personnel allowed for the data collection of the various characteristics of this municipality, the process of receiving C&D waste, challenges of C&D waste management within the municipality and possible waste management strategies. Weighbridge data of all DSW landfills was collected to assess the waste composition that enters the landfills for past 20 years. A waste stream analysis of the weighbridge data was completed. At the Sandop Recovery World site visit, the process of recycling C&D waste was determined. This research combined builders rubble and sand and cover material, called for the purpose of this research Builders rubble mix.

The weigh bridge data of builders rubble and sand and cover material collected from the Cleansing and Solid Waste Unit of DSW landfill sites are shown in Appendix A. Table 3.1 shows the current and projected future tonnages builders rubble and sand and cover material used in this research. The results of the WROSE Model is based on the data provided in this table. The second row of Table 3.1 shows the average of the past five years of builders rubble mix entering each landfill. The average of the years 2015 to 2020 was used as the data shows a fairly constant average among the landfills and the most relevant. The table 3.1 from row three shows the projected tonnages of builders rubbles mix set to enter the various DSW landfill sites. The first row of Table 3.1 shows the years till closure of the various landfills. The projected waste for Bisasar Road Landfill and Mariannhill Landfill is that of 2021's estimated value. Buffelsdraai and Lovu Landfills projected values is the sum of the C&D waste entering these landfills for a 10 year projection. A 10 year projection was used as the Integrated Waste Management Plans of South African municipalities are completed and updated every 10 years. Construction and demolition waste mix of builder's rubble, sand and cover material was the waste stream analysed in this study. The WROSE Model analysis was run twice, once using the average tonnage of the last five years for the current analysis. The other iteration was done with a 10 year projection of the waste tonnages. The 10 year projection was based on the last five years data of the landfills as this accommodates for the most recent activities at DSW such as closing of the Bisasar road and Mariannhill Landfill as well as the opening of Lovu Landfill.

Table 3.1 Waste data, input to the WROSE Model

LANDFILL SITE	BISASAR ROAD	MARIANNHILL	BUFFELSDRAAI	LOVU
Years till closure	1	1	52	32
Current Average Waste (T/annum)	357156	88376	36553	28824
Projected Total Waste (T/annum)	321105	55604	1675238	2639331

3.3.5 Developing and selection of appropriate scenarios and waste management strategies

The data collected, from eThekwini landfill sites and an aggregate recovery company called Sandop Recovery World allowed for the selection of the most appropriate scenarios shown below:

Scenario 1: Landfill disposal

Unsorted C&D waste enters the landfill and is disposed with no practice of recovery or recycling or reuse. This is typical of non-engineered landfills in South Africa. Figure 3.1 shows Scenario 1: Landfill disposal.

Figure 3.1: Scenario 1: Landfill disposal

Scenario 2: Status Quo at DSW

Unsorted C&D waste enters the DSW engineering landfill and goes through a weighbridge. The waste is then manually sorted by landfill workers into contaminated builders rubble and clean builders rubble. The contaminated builders rubble is disposed into the landfill, while clean builders rubble is used for the creation of access roads within the landfill. Figure 3.2 shows Scenario 2: Status Quo

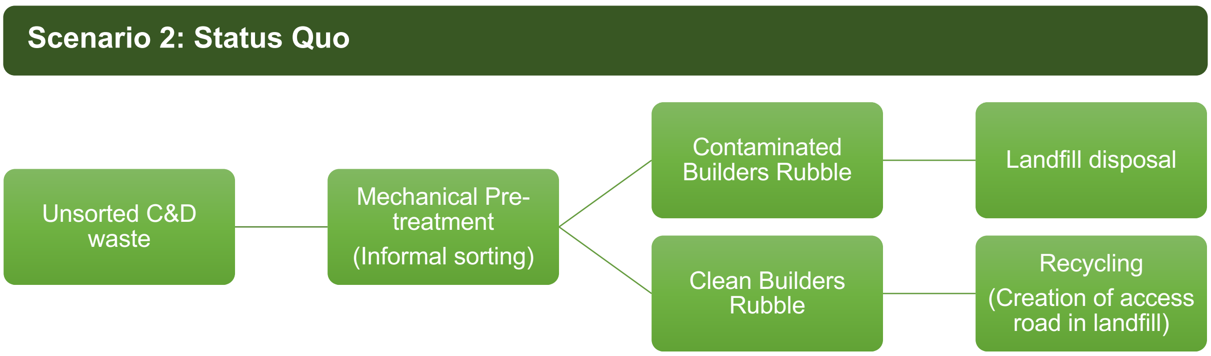

Figure 3.2: Scenario 2: Status Quo

Scenario 3: Recycling

Unsorted C&D waste enters landfill and goes through mechanical pre-treatment of a separation station whereby C&D waste is sorted into contaminated builder rubble and clean builders rubble. The contaminated builders rubble that contains metals, plastic, wood etc is disposed into landfill. The clean rubble that consists of concrete and masonry is sent through a crusher. The material from the crusher is then recycled as aggregates that is sold/given to the roads department to be used as G5, G4,G7 and crusher sand. Figure 3.3 shows Scenario 3: Recycling.

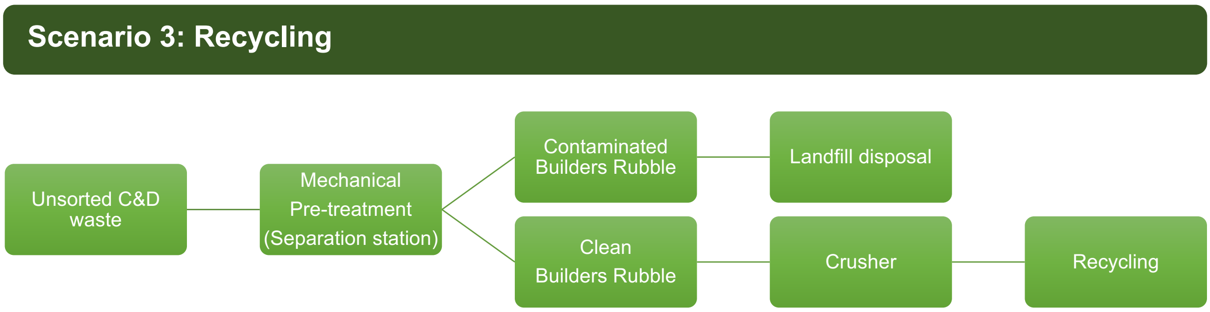

Figure 3.3: Scenario 3: Recycling

Scenario 4: Direct Diversion and Recycling

Unsorted C&D waste enters SandOp Recovery World and DSW Landfills. Unsorted C&D waste that enters SandOp is placed on a weighbridge, then undergoes a mechanical pre-treatment and waste is separated into clean builders rubble and contaminated builders rubble. The Contaminated builders rubble is landfilled. The clean builders rubble is placed through a crusher and the aggregates and fines are used in the creation of concrete which is placed back into the construction industry. At DSW landfills the material undergoes the same procedure as per scenario 3 above. Figure 3.4 represents the Scenario 4: Direct Diversion and Recycling.

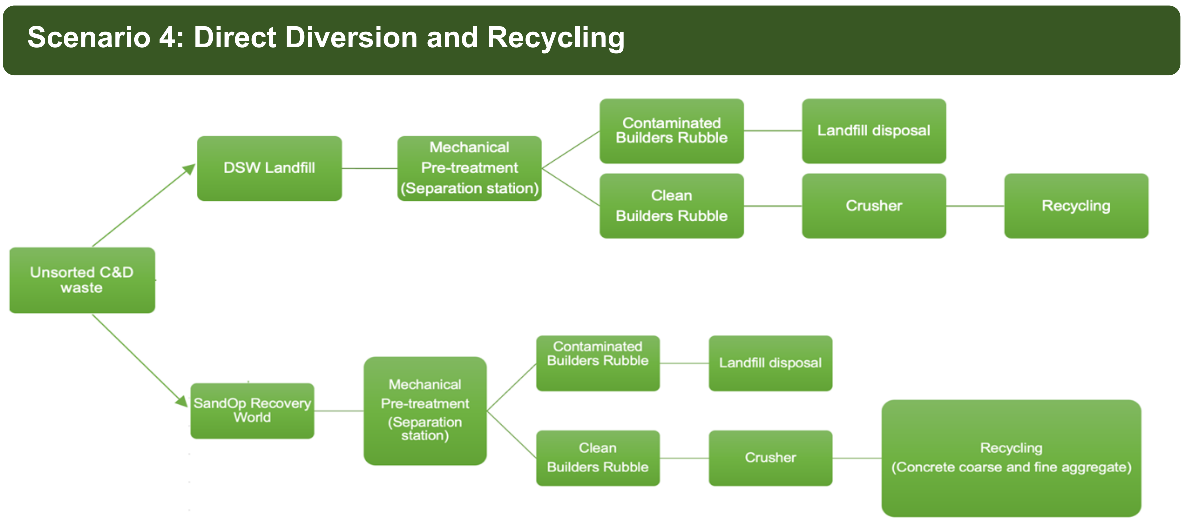

Figure 3.4: Scenario 4: Direct Diversion and Recycling

This scenario was considered as diversion of builders rubble to existing the crushing operation at SandOp Recovery World will alleviate pressure on the municipality in dealing with a portion of C&D waste that is generated on eThekwini. There is potentially a Shongweni Landfill which is currently being licenced and planned. As there are commercial and residential developments planned for the west of Hillcrest/Shongweni (DSW, 2016), diverting C&D waste to SandOp Recovery World would be a well-planned decision to save landfill airspace.

3.3.6 Analysis of scenarios by the WROSE Model

The analysis of the selected C&D waste management scenarios for the eThekwini municipality was done with the use of the WROSE model. The input of the WROSE Model the quantities and quality of the waste stream which was taken from the weighbridge data from the eThekwini municipality landfills. Each scenario includes the various steps and technologies and was analysed to show the provide the most social, economic and environmental scenario due to the chosen indicators for this research. WROSE model allowed for chosen indicators : Landfill air space savings, Economic feasibility and Job creation was determined for each scenario. These four cases were analysed by the WROSE Model under the three pillars of sustainability indicators such as economic, environmental and social impacts.

3.3.6.1 Landfill Space Savings

The environmental analysis is the calculation of the landfill airspace savings generated throughout the different cases. Landfill air space savings is chosen as it is one the most important indicator in the current context as the eThekwini municipality's landfills are running out of air space. This indicator in the WROSE Model determines the amount of landfill airspace the municipality would save by implementing the various waste management practises presented in the scenarios. This would assist the municipality in extending the current life span of its landfills. The equation used to calculate the Landfill Space Savings in the WROSE Model is shown below. A bulk density of 1,6 t/m^3 was assumed for this study (IWMSA, 2018).

$$Landfill\ Space\ Savings\ (m^3) = \frac{waste\ tonnage(t)}{bulk\ density({}^{t}/_{m^3})}$$

3.3.6.2 Job Creation Potential

The social indicator is job creation as it is an important in the local context to alleviate poverty where possible and would be attractive to investors. South Africa has one of the highest rates of unemployment, therefore this indicator will allow the municipality to identify the job creation potential of implementing the various waste management practises presented in the scenarios. The equation used to calculate the Job Creation Potential in the WROSE Model is shown below (Kissoon and Trois, 2018).

$$\frac{Tons\ of\ waste\ per\ day}{Number\ of\ employees} = x\ tons\ of\ waste\ per\ job$$

The job creation potentials were calculated based on the volumes of waste per day and not annually, in order to obtain a clear indication of daily staff requirements per scenario. Hence the annual waste tonnages were divided into daily volumes. The jobs to be created in scenario 3 and 4 would be that of a crusher operator, sorting of C&D waste before crusher, truck drivers, screening, sorting of recycled aggregates and further jobs are created down the life cycle of using recycled aggregates such as laying of the aggregates as subbase, and various other indirect jobs.

3.3.6.3 Economic feasibility

The economic indicator is expressed as economic feasibility. This is an essential indicator as it enhances the scenarios credibility and aids decision makers to determine the positive economic benefits to the eThekwini Municipality that the scenario will provide. The equation used to calculate the Economic Feasibility in the WROSE Model is shown below.

$$Net\ income = revenue - operating\ cost$$

Capital costs was not included in the economic analysis as it was considered that all infrastructure was expected to be existing.

Assumptions used in the WROSE Model are shown in Appendix D.

3.3.7 Results and discussion

The output of the WROSE model is that of Landfill air space savings, Economic feasibility and Job creation. These results are to be displayed in the form of graphs. The various scenarios are to be discussed in terms of which indicators take priority for municipality, therefore providing the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in eThekwini.

3.3.8 Conclusion and Recommendations

The study is to be concluded with recommendations and final words of the research.

3.3.9 Limitations

There are a number of limitations for the conduction of this research. Due to the presence of COVID-19 pandemic Recent data will be skewed due to the halt in construction due to the lockdown restrictions. These was a lack of data on C&D waste generation rates as many municipalities does not report waste generation rates. Currently there is no comprehensive C&D waste characterization in South Africa. Recovery/recycling rates are not well recorded in South Africa. The landfill sites at eThekwini municipality receives waste in an unsorted way.

3.4 Chapter summary

The methodology of this research is shown in this chapter. To optimize construction and demolition waste in eThekwini Municipality a scenario analysis is to be completed through the use of the WROSE Model. The scenarios are formulated through site visits to eThekwini municipality landfills as well as a construction and demolition waste recovery company. The WROSE Model analysis requires various data and therefore limitations were stated in this chapter. All the steps outlined throughout this chapter are used to achieve the various objectives of this dissertation.

CHAPTER 4

4. CASE STUDY

4.1 Introduction

This chapter presents the case study used for this research project. The eThekwini Municipality DSW allowed for the investigation of construction and demolition waste management at one of the landfills. The aim of this chapter is to gain detailed knowledge about the construction and demolition waste management at eThekwini municipality landfill sites.

4.2 eThekwini Municipality

4.2.1 Overview of site

The third-largest metro in South Africa, the eThekwini Municipality (Durban), is a city in the province of KwaZulu-Natal situated along the east coast of South Africa and is home to the busiest port in the African continent. It has an approximate area of 2,297 square km with over 3 442 398 people as per the 2011 Census. Durban Tourism is the leading domestic destination in South Africa. As a result of South Africa hosting the FIFA World Cup in 2010, the estimated visitor number for the financial year 2010/11 was 9,95 million (eThekwiniMunicipality, 2018). Figure 4.1 is a panorama of the eThekwini Municipality.

Figure 4.1 Panorama of eThekwini Municipality Source: (eThekwiniMunicipality, 2019)

The Cleansing and Solid Waste Unit of eThekwini Municipality, Durban Solid Waste (DSW), is the leading provider of comprehensive waste management service with four operational landfills accept over approximately 1.4 million tons of general waste per year generated by the city (DSW, 2016). The landfills are Bisasar Road Landfill, Mariannhill Landfill, Buffelsdraai Landfill and Lovu Landfill. Currently all four landfills accept builders rubble. Figure 4.2 shows geographical location of the various DSW landfills.

Figure 4.2: DSW Landfills within the eThekwini Municipality boundary Source: (eThekwiniMunicipality, 2020a)

In addition to the four landfills, the Cleansing and Solid Waste Unit of eThekwini Municipality operates seven buy back centres, two garden refuse landfills, thirteen garden refuse transfer stations and seven transfer stations. A proposed Shongweni Landfill is being discussed to aid with the increasing waste in eThekwini Municipality. Figure 4.3 shows the DSW waste facilities within the eThekwini Municipality.

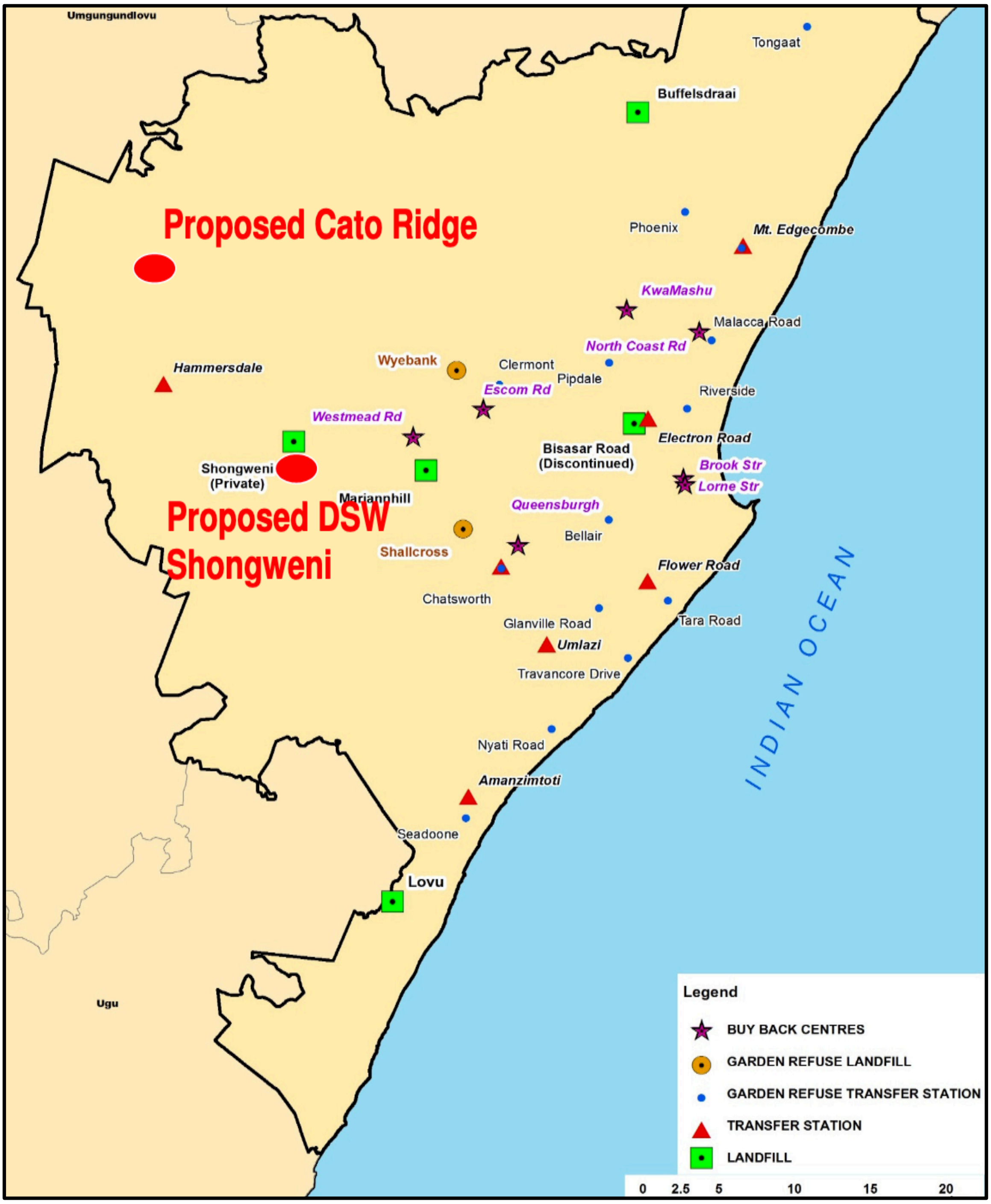

Figure 4.3 DSW waste facilities within the eThekwini Municipality (Source: Moodley, 2019)

Each landfill utilises weighbridge facilities to record waste quantities entering the site. The waste collected at DSW's landfills are classified into 11 categories (DSW, 2016) Table 4.1 displays the description of the waste types that enter the DSW landfills.

Table 4.1 DSW Waste Categories (Source: DSW, 2016)

CODE	PRODUCT TYPE	DESCRIPTION
01	DSW	Domestic, commercial and industrial waste (non-hazardous) that is collected by DSW, including subcontractors
02	GENERAL SOLID WASTE	Domestic, commercial and industrial waste (non-hazardous) that is collected by private contractors
03	GARDEN REFUSE	Discarded plant/tree trimmings, grass cuttings, tree branches and trunks
04	BUILDERS RUBBLE	Discarded non-hazardous material that originated from building or demolishing projects. Includes fragmented concrete, broken bricks and blocks
05	MIXED LOADS	Refers to loads of waste that have mixtures of general solid waste, garden refuse, builders rubble
06	SAND & COVER MATERIAL	Excavated earth that can be used for cover material for the landfill cell
07	PURCHASE COVER MATERIAL	Cover material that has been purchased by DSW for utilisation at the landfill
08	TYRES	Discarded vehicle tyres
09	LIGHT TYPE REFUSE	Includes items such as plastic, polystyrene, insulation material and foam. Refuse that can be windblown easily
10	OTHER	Business waste
11	RECYCLABLES	Refers to loads of sorted recyclable material

4.2.2 Characteristics of DSW Landfill sites

Currently there are some landfills that accepts certain waste due to the status of the landfill. The characteristics of the four landfills operated by DSW is shown below.

4.2.2.1 Bisasar Road Landfill

The Bisasar Road Landfill site was established in May 1980, and it is operated by Durban Solid Waste (DSW) and, located 10 kilometres north of the Durban CBD with an area of

44 ha (DSW, 2016). Figure 4.4 displays the Bisasar Road Landfill Site.

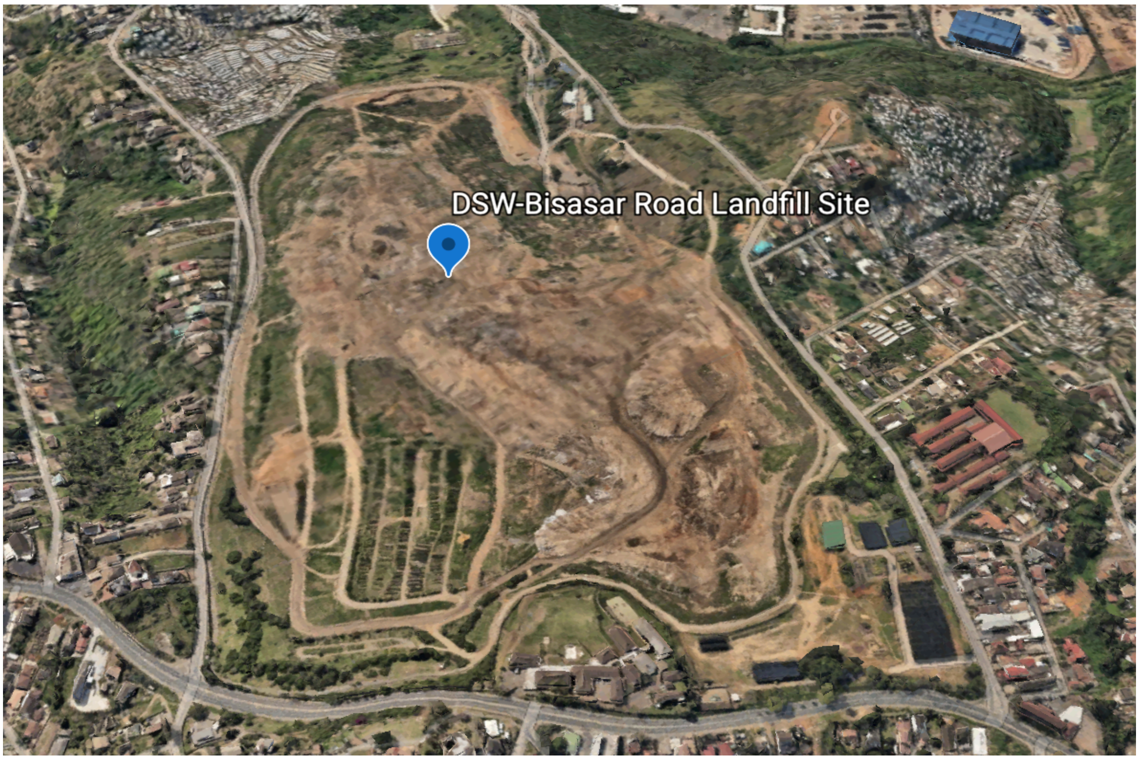

Figure 4.4: Bisasar Road Landfill Site (Source: Google Earth, 2020)

As closure is imminent at Bisasar Road Landfill site, the remaining useful life is just over one a year. 1000 tonnes is received at this landfill (Mooodley, 2019). The site only accepts Builders Rubble, Garden Refuse, and Sand/Cover Material for the progressive capping and is in the process of finalizing detailed closure designs (DSW, 2016). Table 4.2 displays Bisasar Road Landfills' capacity overview.

Table 4.2: Bisasar Road Landfills' capacity overview (Source: Moodley et al., 2019)

LANDFILL SITE	BISASAR ROAD
eThekwini Catchment Area	Central
Design Airspace Capacity (m3)	25,000,000
Remaining Airspace (m3)	140,00
Tonnage Received (t/day)	1000
5Year Airspace Development	0
10Year Airspace Development	0
Remaining Useful Life (Years)	0,5
Status	Closure

4.2.2.2 Mariannhill Landfill

Mariannhill landfill was began operation in 1996 serving the servicing the western catchment of eThekwini. Mariannhill Landfill has an area of 49,5 ha is landfill footprint and the remaining 31ha incorporating the buffer zone due to being recognised as the first landfill conservancy in Africa (Moodley et al., 2019). This site has waste management strategies that is sustainable, eco-friendly engineered “closed-loop” design that treats and reuses landfill emissions(Landfillconservancies, 2008). Figure 4.5 displays the Mariannhill Landfill Site.

Figure 4.5: Mariannhill Landfill Site (Source: Google Earth, 2020)

As a result of the downsizing of the Bisasar Road Landfill Site, the influx of waste to the Mariannhill Landfill Conservancy Site has caused this site to have a remaining useful life estimated at just under a year. To divert waste from entering landfill a private operated small scale recycling scheme for glass, cupboard, paper and plastics was established (DSW, 2016). As of February 2019 Mariannhill Landfill Site will only be accepting: Garden Refuse, Cover Material and Builders Rubble due to imminent closure (eThekwiniMunicipality, 2020b). Table 4.3 Mariannhill Landfills’ capacity overview.

Table 4.3: Mariannhill Landfills' capacity overview (Source: Moodley et al., 2019)

LANDFILL SITE	MARIANNHILL
eThekwini Catchment Area	West
Design Airspace Capacity (m3)	4,400,000
Remaining Airspace (m3)	399,500
Tonnage Received (t/day)	1350
5Year Airspace Development	0
10Year Airspace Development	0
Remaining Useful Life (Years)	1,0
Status	Closure

4.2.2.3 Buffelsdraai Landfill

The Buffelsdraai Landfill serves the northern catchment predominately as well as receiving the bulk of the central areas waste via the Electron Road Transfer Station, becoming one of Durban's busiest landfills with an area of 100 Ha (Moodley et al., 2019). Figure 4.6 displays Buffelsdraai Landfill Site.

Figure 4.6: Buffelsdraai Landfill Site (Source: Google Earth, 2020)

The first ten years of Buffelsdraai Landfills' operation recorded 400 tonnes of waste a day. Then tonnage of waste entering landfill has increased to 1000 tonnes of waste a day as a result of the decommissioning of Bisasar Road Landfill. The landfill is estimated to have approximately 51 years remaining useful life. Table 4.4 displays capacity overview of Buffelsdraai Landfill Site.

Table 4.4 Buffelsdraai Landfills' capacity overview (Source: Moodley et al., 2019)

LANDFILL SITE	BUFFELSDRAAI
eThekwini Catchment Area	North
Design Airspace Capacity (m3)	45,000,000
Remaining Airspace (m3)	39,097,000
Tonnage Received (t/day)	2135
5Year Airspace Development	4,000,00
10Year Airspace Development	8,100,000
Remaining Useful Life (Years)	51
Status	Expansion

4.2.2.4 Lovu Landfill Site

The Lovu Landfill site was recently commissioned site in 2014 serving the south catchment of eThekwini with an area of 260 Ha (Moodley et al., 2019) Figure 4.7 displays the Lovu Landfill Site.

Figure 4.7 Lovu Landfill Site (Source: Google Earth, 2020)

Lovu Landfill has also experienced an expeditious increase in waste volumes emerging as the other landfills are approaching closure, this site receives 480 tonnes of waste a day with the remaining useful life of 32 years (Moodley et al., 2019). Table 4.5 displays Lovu Landfill's capacity overview.

Table 4.5: Lovu Landfills' capacity overview

LANDFILL SITE	LOVU
eThekwini Catchment Area	South
Design Airspace Capacity (m3)	9,660,000
Remaining Airspace (m3)	8,979,335
Tonnage Received (t/day)	770
5Year Airspace Development	2,100,00
10Year Airspace Development	6,200,000
Remaining Useful Life (Years)	32
Status	Expansion

The eThekwini Municipality has a limited landfill airspace capacity, DSW has various waste management strategies in place to increase the remaining useful life of its landfills. The context of waste management in eThekwini Municipality is shown below.

4.2.3 The context of waste management in eThekwini Municipality

Recently the integrated waste management plan for DSW has been updated. It is estimated solid waste generation in Durban is 3400 tonnes a day therefore Durban approximately generates 1,4 million tonnes of solid waste a year. DSW has an effective waste collection rate of 95%, although this shows that there is a scarce diversion of waste from landfills. Kerbside collection occurs once a week by Rear End Loaders. Waste entering landfills are not separated, therefore making it difficult to recycle the waste. Figure 4.8 shows DSW operations across eThekwini Municipality

Figure 4.8: DSW operations across eThekwini Municipality Source: (DSW, 2007)

The eThekwini municipality has implemented a recycling initiative by supplying households with three refuse bags in an effort to separate waste at source. Black bags for domestic waste, blue bags for garden refuse and orange bags for recycling materials, encouraging residents to separate waste, therefore, diverting waste for landfills. The collected waste is transported to a materials recovery facility (MRF), which is a mechanical or manual separation plant, specialising in extracting recyclables such as plastic, glass and paper whereby the useful waste is given extended life. Figure 4.9 illustrates the context of waste management in the eThekwini Municipality.

Figure 4.9: Waste management context in eThekwini Municipality (Source: Moodley et., 2019).

Previous studies have shown that among all the different types of waste material that enters the eThekwini's landfill sites, the C&D waste represents a significant portion of the main flow (Zedda et al., 2014).

4.2.4 Status Quo of C&D waste management in DSW landfill sites.

A site visit to the Bisasar Road landfill and an interview with the Deputy Head of Plant and Engineering at eThekwini Municipality, resulted in an in-depth knowledge of the management of construction and demolition waste at DSW's various landfills.

Construction and demolition waste consumes approximately 40% of landfill airspace at DSW Landfills due to the dense and bulky in nature. All four major DSW Landfills accept builders rubble. Bisasar Road Landfill only accepts only accept garden refuse, builders rubble and cover material. Mariannhill accepts builders rubble as well as all waste mentioned in Table 4.2, although this landfill is to only accept garden refuse, builders rubble and cover material from the 1st of February 2020. Buffelsdraai and Lovu Landfills accepts builders rubble with all other waste categories mentioned in Table 4.2. DSW in an effort to preserve the valuable landfill airspace and increase landfill operational lifespan, DSW operates Shallcross Garden Site which is a small scale landfill that only accept garden refuse, builders rubble and cover material.DSW defines "clean" builders rubble as concrete and masonry waste and "contaminated" builders rubble as concrete and masonry waste mixed with other construction waste such as dry wall, scrap metal, wood etc. The builders rubble that enters the Bisasar road landfill is "clean" builders rubble, while "contaminated" builders rubble are sent to Lovu and Buffelsdraai landfill.

Trucks caring builders rubble enters DSW's landfill where the weigh bridge is used to calculate the volume of waste being deposited. The tariff is estimated to be R 75,08 per ton of builders rubble. Figure 4.10 shows a vehicle entering landfill on the weighbridge.

Figure 4.10 Vehicle on DSW weighbridge

Thereafter the weighbridge, the builders rubble is evaluated and the “clean” builders rubble that contains masonry and concrete is either stockpiled or directly used to create access roads at the landfill. The stockpile of rubble is kept to be transported to other landfills that need rubble for the creation of access roads at these landfills. DSW landfills do not do any sorting of builders rubble i.e. removing of scrap metal, dry walls, timber etc. Rather the “contaminated” builders rubble that contains all waste during construction such as plastic bags, ceiling boards, dry wall etc are sent straight to working face. The working face at these DSW landfill sites are that whereby waste is processed , such processes includes : compaction of the waste by bull dozer , shaping the waste and covering the waste by rear end loader. Figure 4.11 shows the working face in process at landfill site.

Figure 4.11: Working face at DSW landfill

The main use of rubble at DSW’s landfills is to create access roads as to strengthen and firms the platforms on which the vehicles are offloading and travelling on, as when there is rainfall, the rubble acts as strength function to avoid slope failure. The DSW’s transfer stations at does not process any construction and demolition waste, only domestic waste. Figure 4.12 shows the slopes of the landfill which strengthened by builders rubble.

Figure 4.12: Slopes at DSW landfill

4.2.5 Challenges at DSW on Construction and demolition waste management

There are many challenges that municipalities face with regards to waste management. At DSW construction and demolition waste management is affected by the following challenges: DSW receives “contaminated” builders rubble as the public does not to sort waste. Therefore builders rubble received includes all waste during construction such as plastic bags, ceiling boards, dry wall. This limits the use and decrease the value of the concrete and masonry which can be recovered and placed back into the construction industry. There is no crushing facility or sorting of builders rubble at DSW as there is not enough data on the value and quality standards of recycled aggregates in South Africa.

As DSW has stated that there is not enough data and information about recycled aggregates, A construction and demolition waste recovery company called Sandop Recovery World was also used as a case study to obtain that various data needed for creation of the various scenarios which were analysed by the WROSE Model to show DSW the steps to take in recovering construction and demolition waste.

4.3 Sandop Recovery Company

4.3 1 Overview of site

Sandop is an aggregate recovery company that is privately owned, operating in Cato Ridge within the eThekwini Municipality . Sandop is a licenced concrete and demolition waste processing operation with over 40 years’ experience in this field. concrete and demolition waste is recycled for reuse and extracting top grade materials such as fine, medium and coarse sand's. Figure 4.13 shows the Sandop site with various machinery in Durban

Figure 4.13: Sandop Recover World site

The three scenarios involve DSW Bisasar Road Landfills with the fourth scenario involving SandOp recovery World to divert an waste entering DSW landfills. SandOp is located in Cato Manor as shown in Figure 4.14 below.

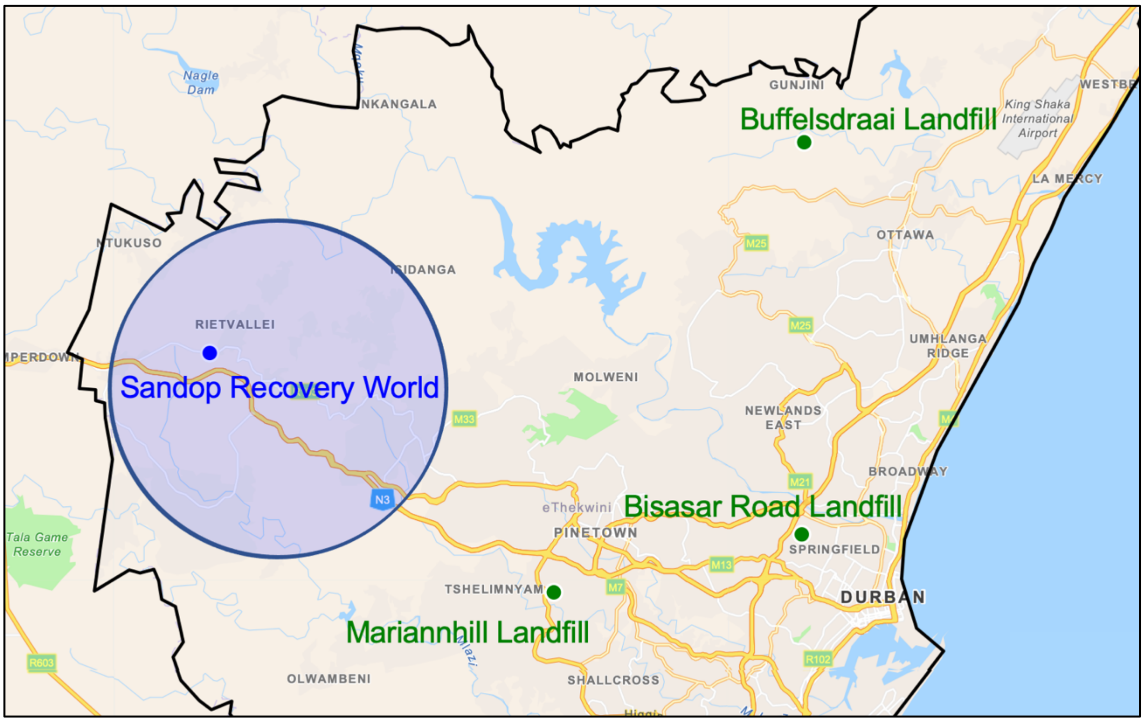

Figure 4.14 SandOp location in Cato Manor

4.3.2 Status Quo of Sandop Recovery Site

Builders rubble and concrete waste is collected and transported from construction and demolition sites to the Sandop recovery site whereby various processes are completed to beneficiate the demolition waste. The builders rubble is sorted to extract concrete which is then placed in crusher to be broken down into various aggregate sizes. The aggregate is separated into different fractions such as large pebbles, sand and even dust which can all be used again in the construction industry.

Sandop has placed their aggregates into three categories:

A Class, B Class and C Class.

A Class:

Is the aggregates are of the highest value and can be used in Recycled aggregate concrete. Sandop has conducted the different tests to prove that the A class aggregates concrete has similar properties to that of concrete made up if virgin materials. A class is when the original strength, mix is known and the concrete is less contaminated and is deconstructed with the correct machinery that does not heavily decrease the value of the concrete.

B Class:

Is whereby the origin and properties of the concrete is known but no documents to prove it. Therefore the quality of aggregate is decrease hence aggregate used in medium value operations such as aggregate for pavements.

C Class:

Is whereby there is no information about the origin and properties of the concrete waste. This causes the quality of the aggregates to be compromised. This aggregate is used in low value operations such as concrete for cover up, pebbles.

4.3.3 Process of C Class aggregate recovery

This research is to focus on the builders rubble that enters the landfill, therefore focusing on the Class C. According to the classes presented by Sandop Recovery World: Concrete goes through crusher then goes through belt that concrete goes through magnet that extracts the steel and thrown the stell into a bin below. The concrete goes into machine(from Ireland) that has sieves inside it and grades the concrete from 10 to 19 mm stones. This concrete is then used for concrete sealing and recycled aggregate pavements.

4.4 Chapter summary

This chapter shows the case studies used in this research. The data collected from the various site visits is be to analysed by the WROSE Model to optimize construction and demolition waste at eThekwini landfills.

CHAPTER 5

5. RESULTS AND DISCUSSION

5.1 Introduction

This chapter presents the data collected for this study. This data includes weighbridge data from the four DSW operated landfills in the eThekwini municipality as well as the WROSE Model analysis of the four scenarios of Construction and Demolition waste management practices. The analysis consisted of an evaluation of the three pillars of sustainability which are the environmental, economic and social impacts of each scenario. Landfill Space Savings, Economic Feasibility and Job creation are the three indicators used in the WROSE Model analysis.

5.2 Weighbridge data analysis

DSW operates four landfill sites throughout the eThekwini municipality, such as Bisasar road, Mariannhill, Buffelsdraai and the Lovu landfill. DSW uses a weighbridge to measure and record the quantities of the various waste streams entering the landfills.

The data available included 20 years of weighbridge records for the four DSW landfills in eThekwini. Builders rubble, sand and cover material was the main waste streams that was analysed for this research.

5.2.1 Total general waste at DSW

The total general waste entering DSW landfills throughout the various years is shown in Figure 5.1. In 2019 builders rubble was one of the highest waste contributor with approximately 100 000 tonnes. The largest percentage contribution of builders rubble was that of in 2010 with 13% due to the FIFA World Cup infrastructure. Builders rubble, sand and cover material are two major waste streams entering DSW landfills, these two waste streams reaches approximately 40% of the total amount of waste entering the landfills. Builders rubble, sand and cover material and purchased cover material has shown an increasing contribution to waste the enters onto landfills, as these materials help with building the landfills of DSW. Builders rubble, sand and cover material and purchased cover material composed of 33% of the total waste entering landfills in 2001, growing to 41,1% in 2019. This growth is due to the increase in C&D operations in the eThekwini municipality as a result of urbanisation throughout South Africa.

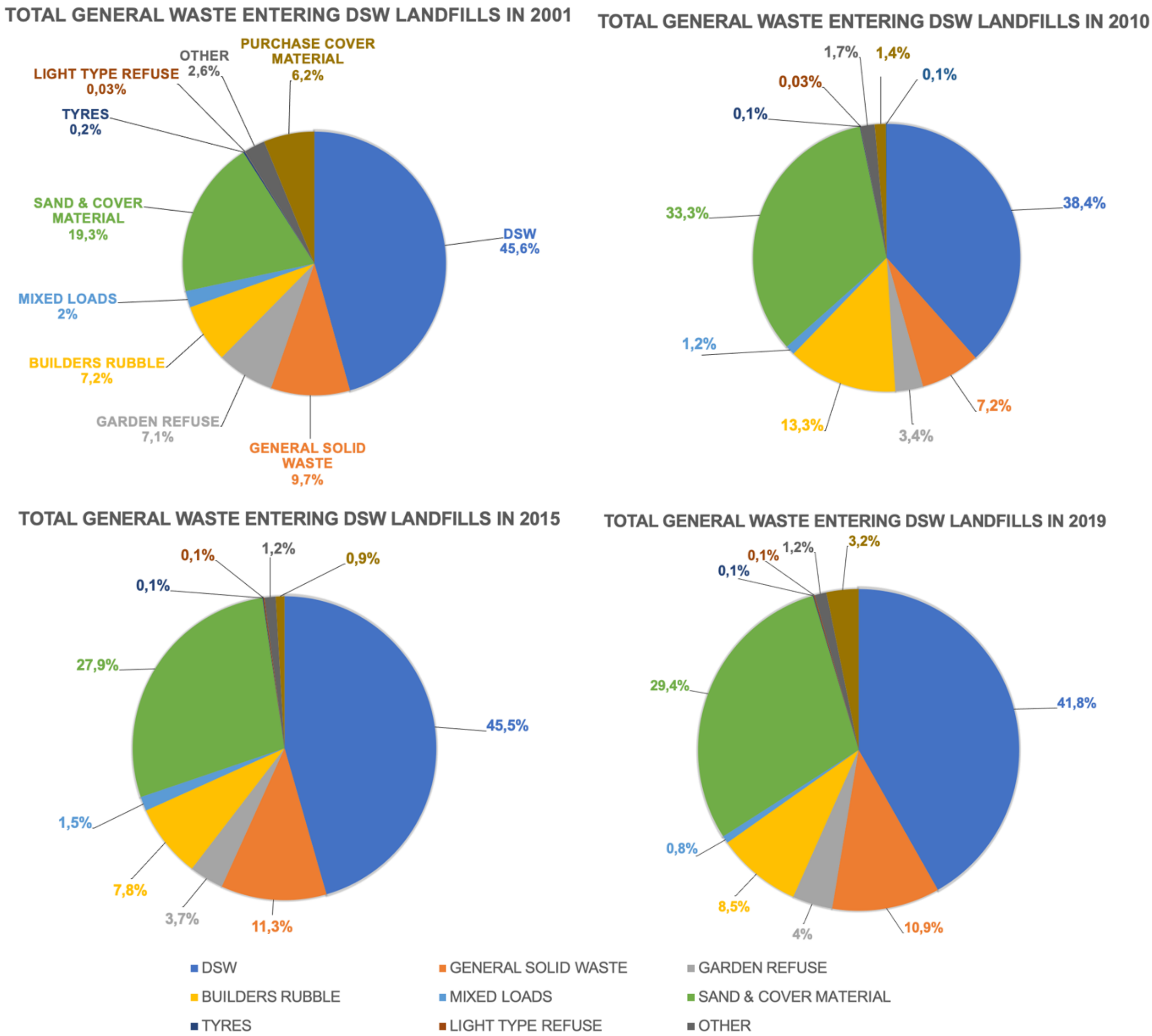

Figure 5.1 Total general waste entering DSW landfills over the past 20 years

5.2.2 Builders rubble at DSW

The Figure 5.2 illustrates the total builders rubble waste entering DSW landfills over the past 20 years and future predictions. As South Africa developed and increased in urbanisation especially in eThekwini, construction and demolition waste increased as the graph shows an increase from 2001. Builders rubble entering the landfills peaked at 180 000 tonnes during 2009 and 2010 due to the increase in construction for the 2010 FIFA World Cup. After 2010 South Africa maintained an average of around 92 741 tonnes a year. The trendline present in Figure 5.5 predicts that there will be an increase in the disposal of builders rubble at landfills, the overall increase rate of builders rubble entering DSW landfills is 1000 tons per year. It approximated that builders rubble will reach 120 000 tonnes per annum in 2030. DSW landfills cannot handle this estimated future amount of builders rubble as landfills are approaching closure and builders rubble is dense and bulky occupying a significant amount of landfill airspace.

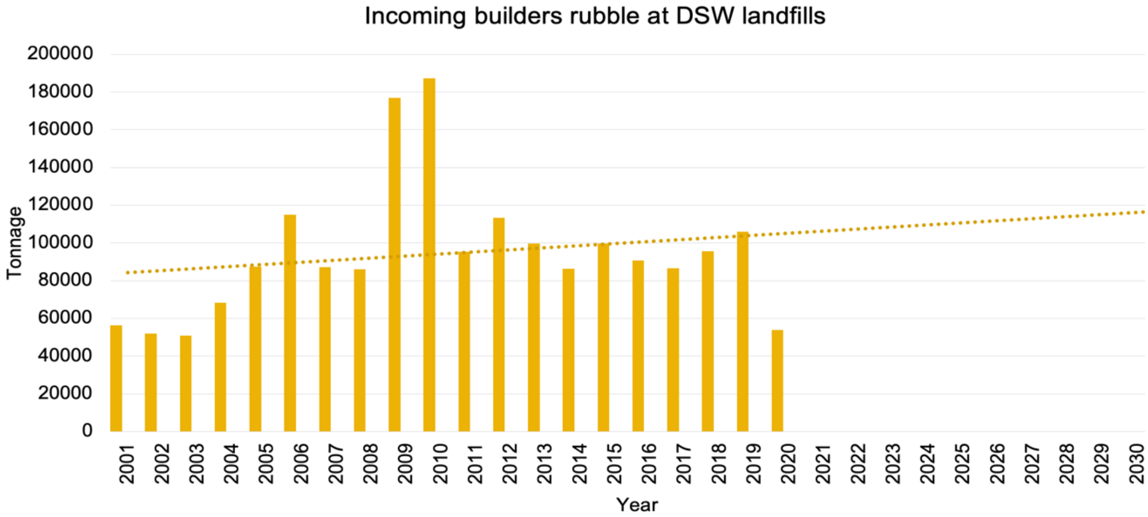

Figure 5.2: Incoming Builders rubble at DSW landfills

5.2.3 Sand and Cover material at DSW

Sand and Cover material is excavated earth that DSW uses for cover material for the landfill cells. Sand and cover material is one of the highest waste contributor to DSW landfills as shown in Figure 5.1, usually contributing an average of 28% to the overall waste. Figure 5.3 shows the incoming Sand and Cover material at DSW landfills over the past 20 years and a 10 year future prediction. The Figure illustrates that since 2001 sand and cover material has generally increased over the years with sand and cover material reaching a peak of 550 000 tonnes in 2012. The increase in construction activities due to general urbanization and a surge construction activities due to new infrastructure needed for the 2010 FIFA World Cup may account for this increase as well as the surge in new infrastructure. Sand and cover material declined from 2013 to 2015 and increased in the following years. The overall increase rate of sand and cover material entering DSW landfills is 10 800 tons per year. The trendline of the graph indicates that cover material, excavated earth and sand are expected to increase reaching approximately 620 000 tonnes per annum in 2030.

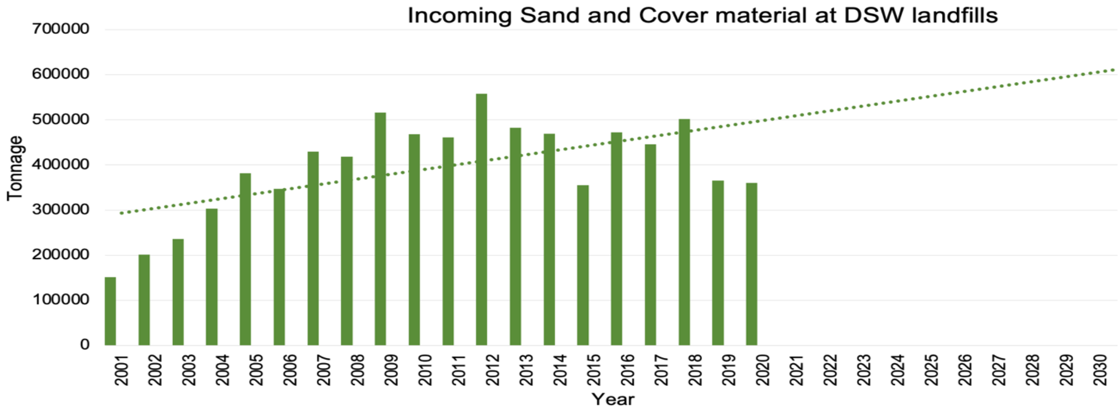

Figure 5.3: Incoming Sand and Cover material at DSW landfills

5.3 C&D waste at various landfills

Waste materials vary in different landfills. For this study an in-depth analysis of the weighbridge data for construction and demolition waste at each landfill shown below. Currently all DSW landfills accept construction and demolition waste. Figure 5.4 shows Builder rubble at various DSW Landfills over the past 5 years.

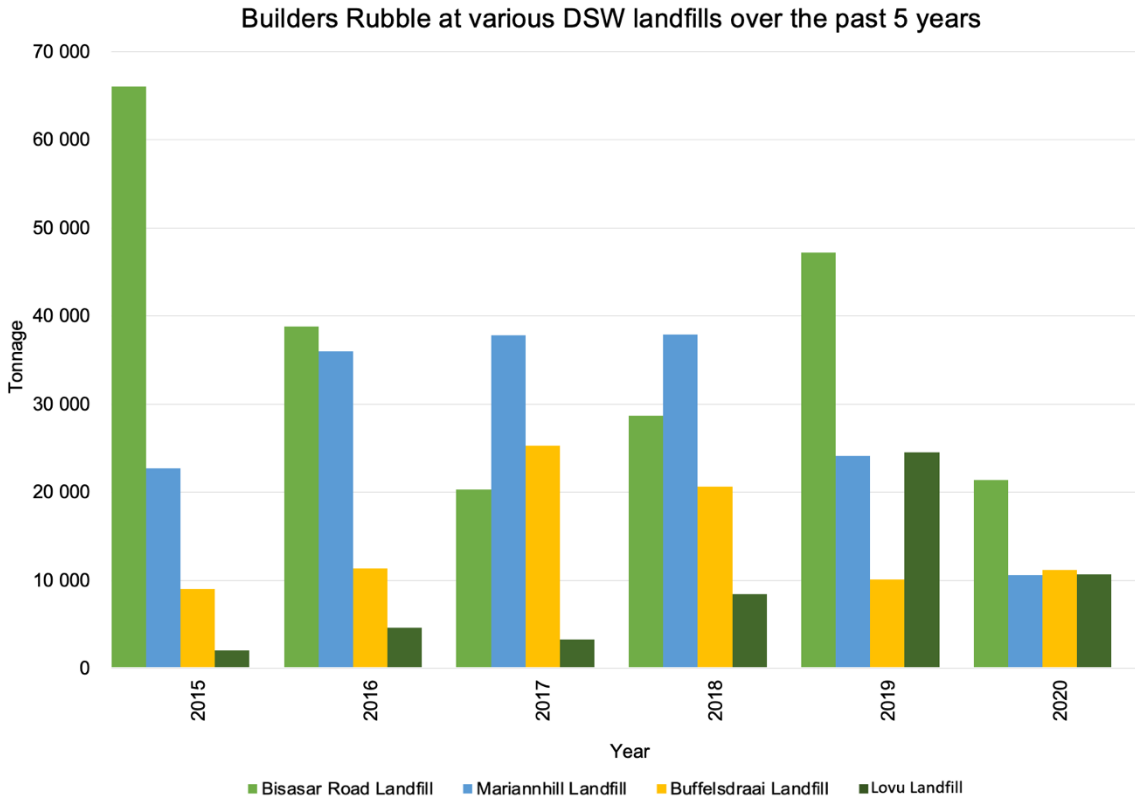

Figure 5.4:Builders rubble at various landfills over the past 5 years

Figure 5.4 exhibits that builders rubble remained the most constant throughout the 5 years at Mariannhill Landfill with approximately 28 000 tonnes per annum. Bisasar Road Landfill has received the most builders rubble receiving a total of over 222 000 tonnes over the past 5 years alone, 2016 shows a decrease in builders rubble entering Bisasar Road Landfill due to the opening of Lovu Landfill and operations of other landfills as well as the Shallcross Garden Site. The construction industry hasn't been immune to Covid-19 impacts as there was a decrease in builders rubble in 2020 as construction may have been halted for a few months or decrease in new projects due to the uncertain future creating high risk for expansion. Buffelsdraai landfill has seen an increase of builders rubble entering landfill with a total of over 87 000 tonnes of waste entering landfill over the past 5 years. Across all landfills the total builder rubble received over the just the past 5 years are approximately more than half a million tonnes. This indicates that recovering builders rubble will increase the landfill airspace of the landfills in eThekwini.

An in-depth look at construction and demolition waste at each landfill is exhibited below.

5.3.1 Bisasar Road Landfill

The Bisasar Road Landfill has been operating for over 40 years, serving the central city of the eThekwini municipality. Figure 5.5 shows the incoming builders rubble at Bisasar Road Landfill over the past 20 years.

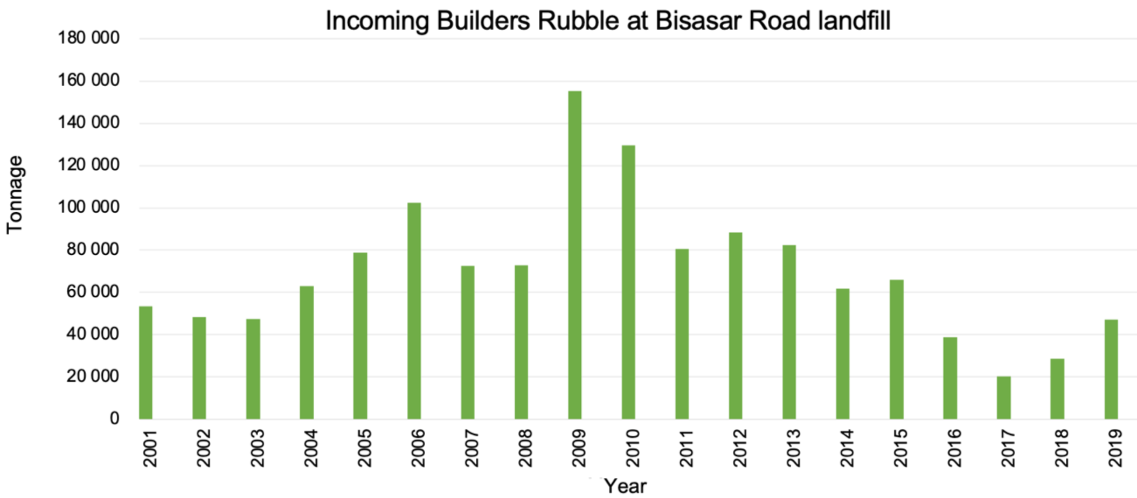

Figure 5.5: Incoming builders rubble at Bisasar Road Landfill

The graph shows an increase in builders rubble in 2009 and 2010 due to construction of various infrastructure needed for the 2010 world cup held in SA. The tonnage of builders rubble decreased from 2010 at Bisasar Road Landfill due to the operations of other landfills, hence builders rubble was diverted from Bisasar Road Landfill to the other landfills that have been created. As Bisasar Road Landfill nears the end of lifespan, with just 2 years of remaining useful life, resulting in progressive capping, operations have downsized only accepting accepts Builders Rubble, Garden Refuse and Sand/Cover Material. Hence C&D waste has increase in 2019 (Moodley, 2019).

The incoming C&D waste at Bisasar Road Landfill is shown in Figure 5.6. Builders rubble, sand and cover material and purchased cover material aided in building Bisasar Road Landfill. Figure .. shows purchased cover material was a large amount at the first few years of the landfill as the amount of sand and cover material entering the landfill in those early year was insufficient. As the amount of sand and cover material increased, the amount purchase cover material decreased.

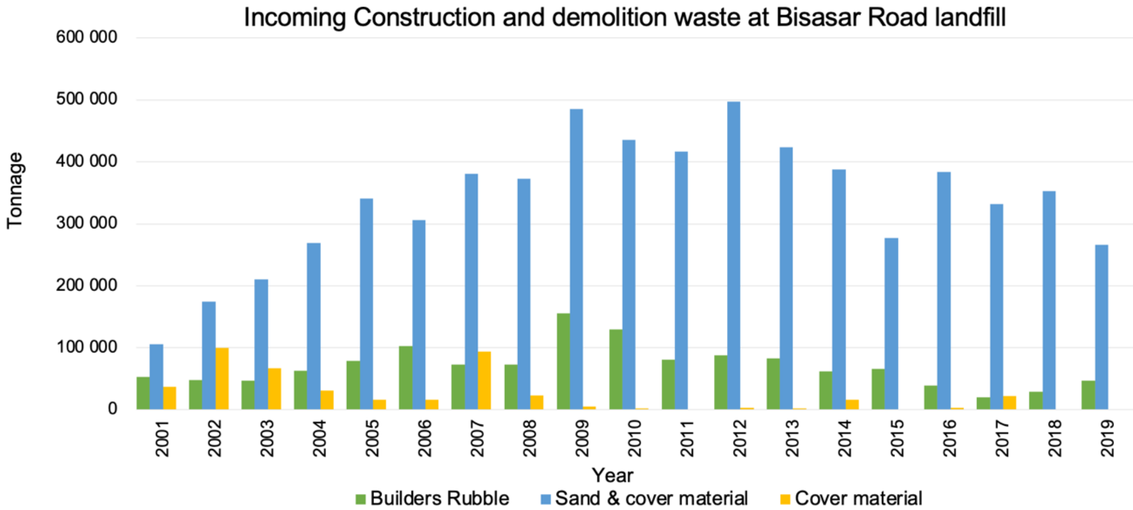

Figure 5.6: Incoming C&D waste at Bisasar Road Landfill

Builders Rubble occupies a large amount of airspace at Bisasar Road Landfill. Figure 5.7 illustrates the waste entering Bisasar Road Landfill over the past five years. This figure shows that builders rubble is the fourth highest contributor to the total waste entering this landfill with 7%. Combining Sand and Cover material with Builder Rubble causes C&D waste contribution to be the highest contributor at the Bisasar Road Landfill.

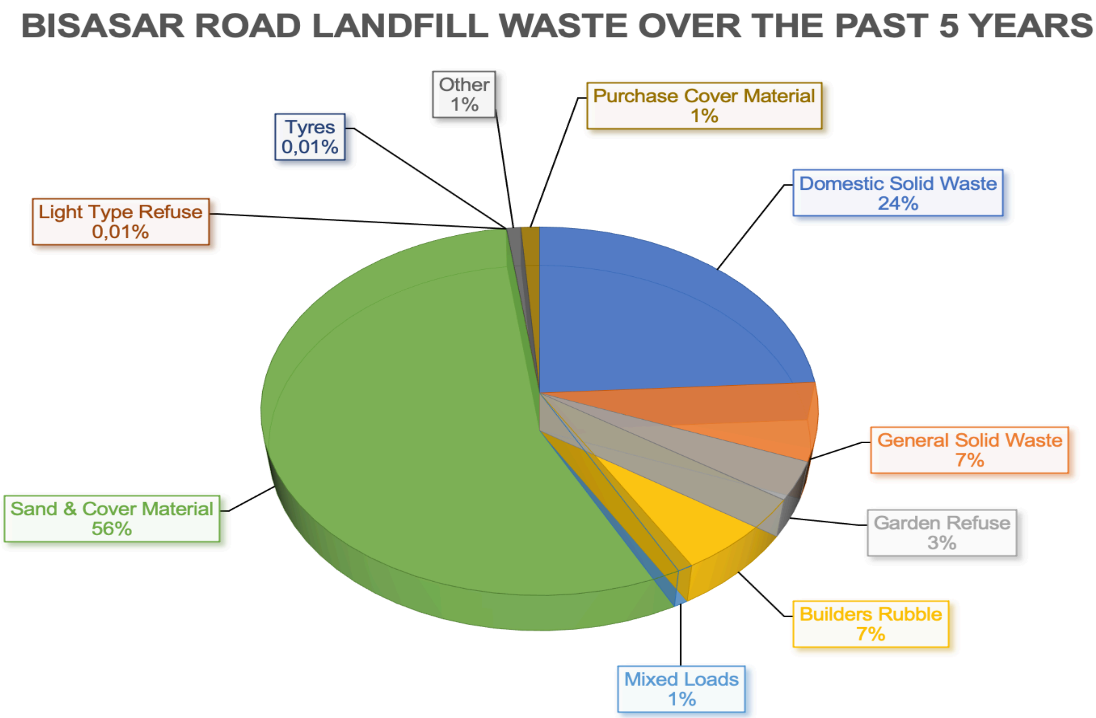

Figure 5.7 Bisasar road landfill waste over the past 5 years

5.3.2 Mariannhill landfill

The Mariannhill landfill was established in 1996 and was aimed to serve the western areas of eThekwini municipality. Figure 5.8 shows the incoming builders rubble at Mariannhill landfill over the latest 20 years. The graph shows gradual increase in builders rubble from 2001 due to urbanisation causing an increase on construction activities. This increase has placed the landfill at critical airspace capacity, causing the landfill life estimation of the Mariannhill landfill to be just over a year. In 2016 there was a surge of builders rubble entering Mariannhill landfill due to Bisasar Road Landfill nearing its end of life and therefore discontinuing the acceptance of various waste. Although Bisasar Road Landfill but still accepted builders rubble many companies may have started to use Mariannhill landfill to dispose of their builders rubble.

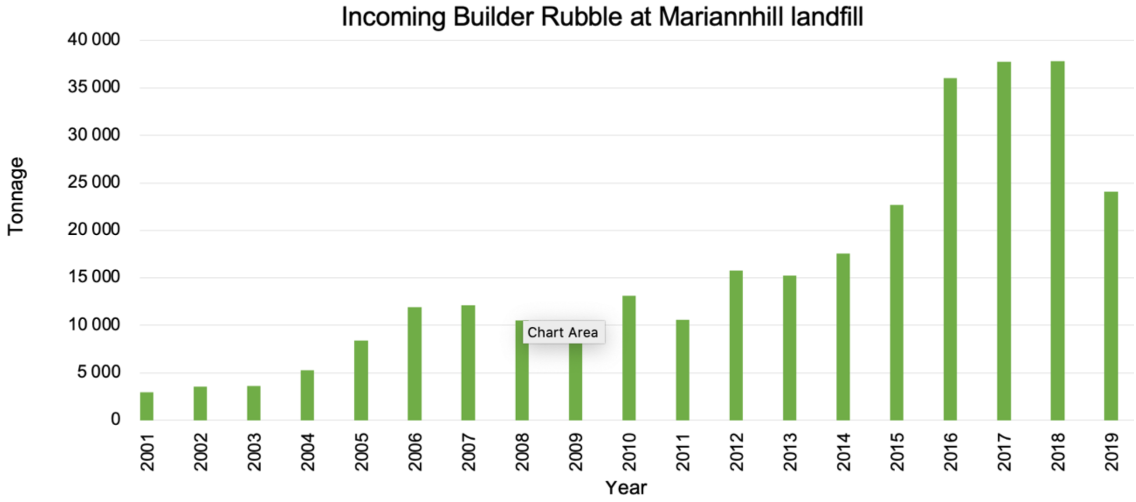

Figure 5.8: Incoming builders rubble at Mariannhill landfill

The incoming C&D waste at Mariannhill landfill is shown in Figure 5.9. Builders rubble, sand and cover material and purchased cover material aided in building Mariannhill landfill. Figure 5.9 is indicates that a significant amount of purchased cover material enters Mariannhill landfill as compared to Bisasar Road Landfill. The amount of sand and cover material and purchase cover material are similar for majority of the years. As Mariannhill Landfill is due for closure with approximately one year of remaining useful life, the landfill has now only been accepting Builders rubble, Garden refuse and Sand/Cover Material.

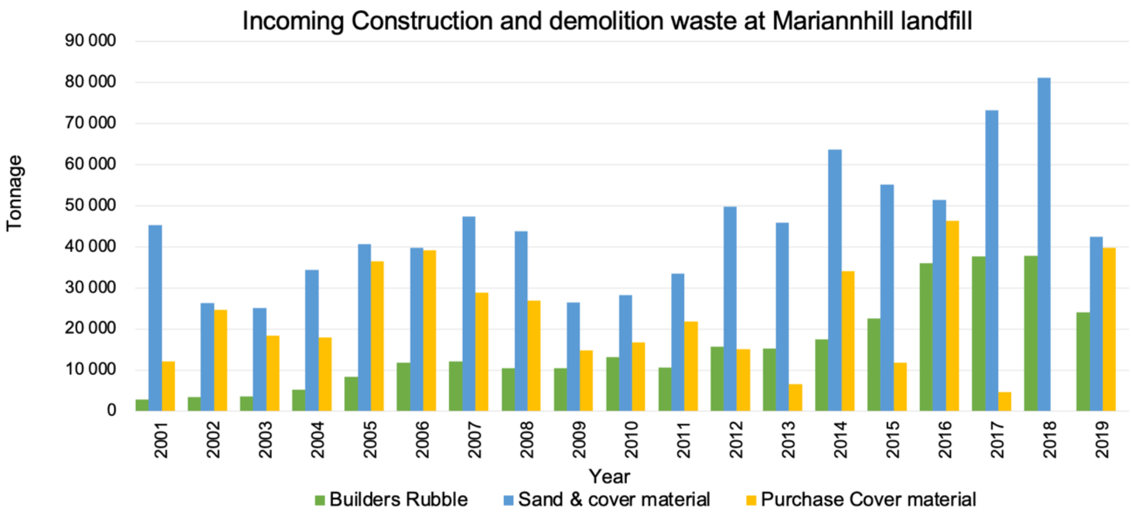

Figure 5.9: Incoming C&D waste at Mariannhill landfill

5.3.3 Buffelsdraai landfill

Buffelsdraai landfill began operation in 2006 and serves the northern regions of the eThekwini municipality as well as receives bulk waste from central areas through the electron road transfer station. Figure 5.10 displays the waste entering Buffelsdraai landfill over the past five years. C&D waste is the second highest contributor to the waste entering Buffelsdraai Landfill by combining builders rubble and sand and cover material.

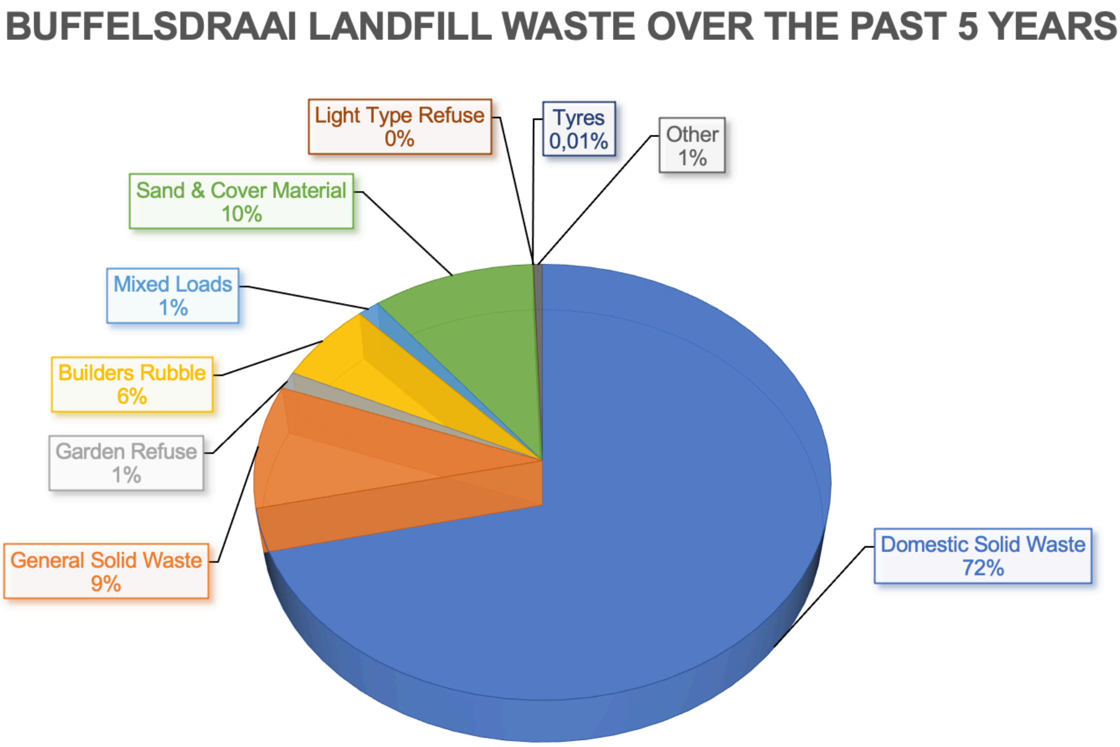

Figure 5.10: Buffelsdraai landfill waste over the past 5 years

Figure 5.11 shows the incoming builders rubble at Buffelsdraai landfill over the past 14 years of operation. The graph shows a surge in builders rubble due to the construction of 2010 FIFA world cup infrastructure. Buffelsdraai landfill receives smaller quantities of builders rubble as compared to the other major landfills in eThekwini averaging 11387 tons of builders rubble a year. The graphs depict as increase 2017 due to waste being diverted from Mariannhill and Bisasar landfill.

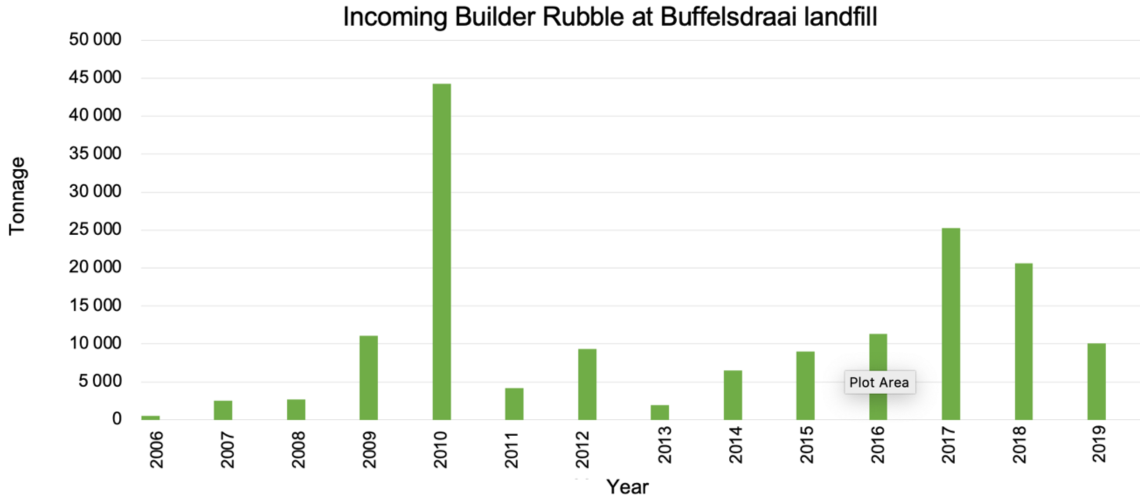

Figure 5.11 Incoming builders rubble at Buffelsdraai landfill

The incoming C&D waste at Buffelsdraai landfill is shown in Figure 5.12. Builders rubble, sand and cover material and purchased cover material aided in building Buffelsdraai landfill. The graph displays the increase of sand and cover material throughout the years of operation, while purchased cover material decreased to extremely small amounts as the landfill operates.

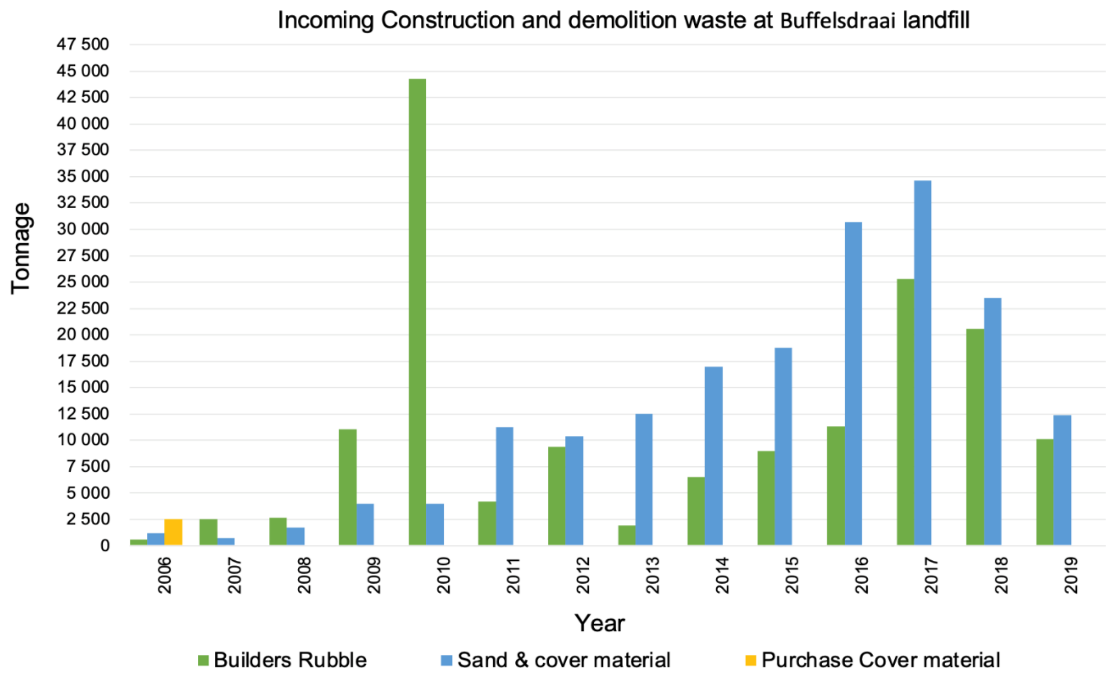

Figure 5.12: Incoming C&D waste at Buffelsdraai landfill

5.3.4 Lovu landfill

The recently developed Lovu landfill, commissioned in 2014 serving the south of the eThekwini Municipality. Figure 5.13 illustrates the waste entering Bisasar Road Landfill over the past five years. C&D waste is the third highest contributor to the waste entering Buffelsdraai Landfill by combining builders rubble and sand and cover material.

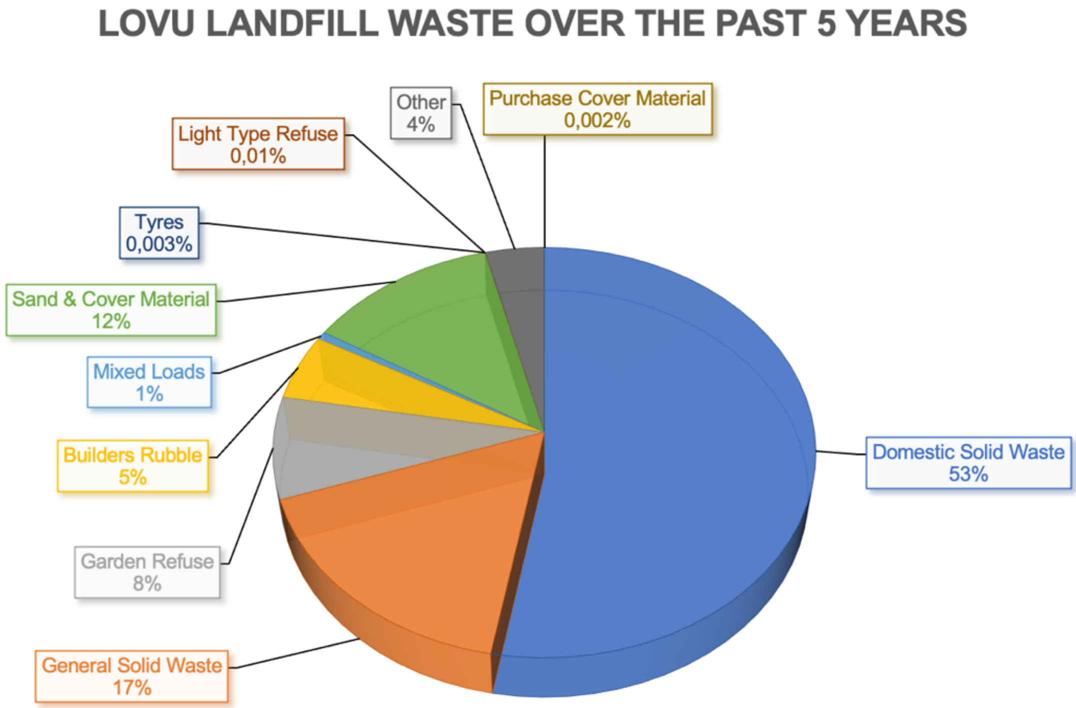

Figure 5.13: Lovu Landfill waste over the past 5 years

Figure 5.14 displays the incoming builders rubble at Lovu landfill over the 6 years of operation. Builders rubble has been gradually increasing since the opening of the landfill, as most of the builders rubble is being used for capping at the various other landfills.

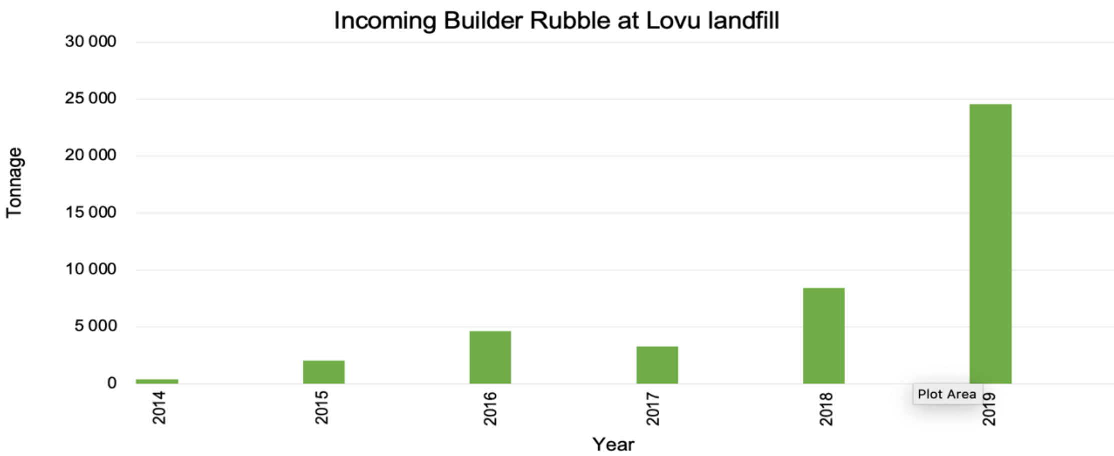

Figure 5.14: Incoming builders rubble at Lovu landfill

However, this landfill has seen a rapid increase in the volumes of waste in 2019 due to other landfills closing down of the other landfills. The incoming C&D waste at Buffelsdraai landfill is illustrated in Figure 5.15. Builders rubble, sand and cover material aided in building Lovu landfill. The graph reveals that Lovu Landfill has not purchased cover material. Both builders rubble and sand and cover material tonnages have increased through the years with a surge in 2018 due to the other landfills nearing the end of life, causing most of the waste to be diverted to Lovu landfill.

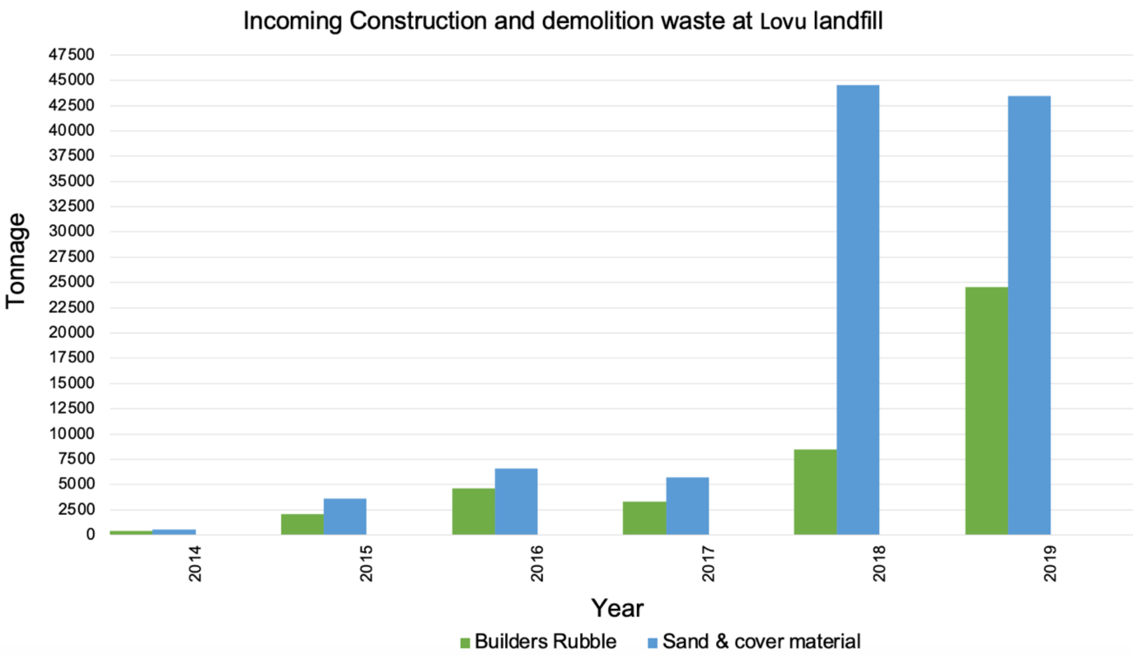

Figure 5.15: Incoming C&D waste at Lovu landfill

5.4 Covid-19 impact on waste at DSW

COVID-19 pandemic has impacted the society functions and therefore this creates a knock on effect on the waste generated in a world. Figure 5.16 Focuses on the difference in waste tonnages between 2019(pre-covid-19) and 2020 (post covid-19).

The graph indicates an increase in majority of the waste categories in 2020 as compared to 2019 tonnages. DSW, a waste category at the eThekwini municipality which consists of domestic, commercial and industrial waste, showed an increase in tonnage. This increase may be due to the National lockdown levels causing the public to stay at home resulting in an increase of domestic waste in 2020. Builders rubble and Sand and cover material showed an increase in tonnage in 2020 as compared to 2019, although construction activities were halted for approximately one to two months due to National lockdowns. Weighbridge data is important and allows for comparison of the various different waste at different years . The WROSE Model utilizes this weighbridge data as an input into the model.

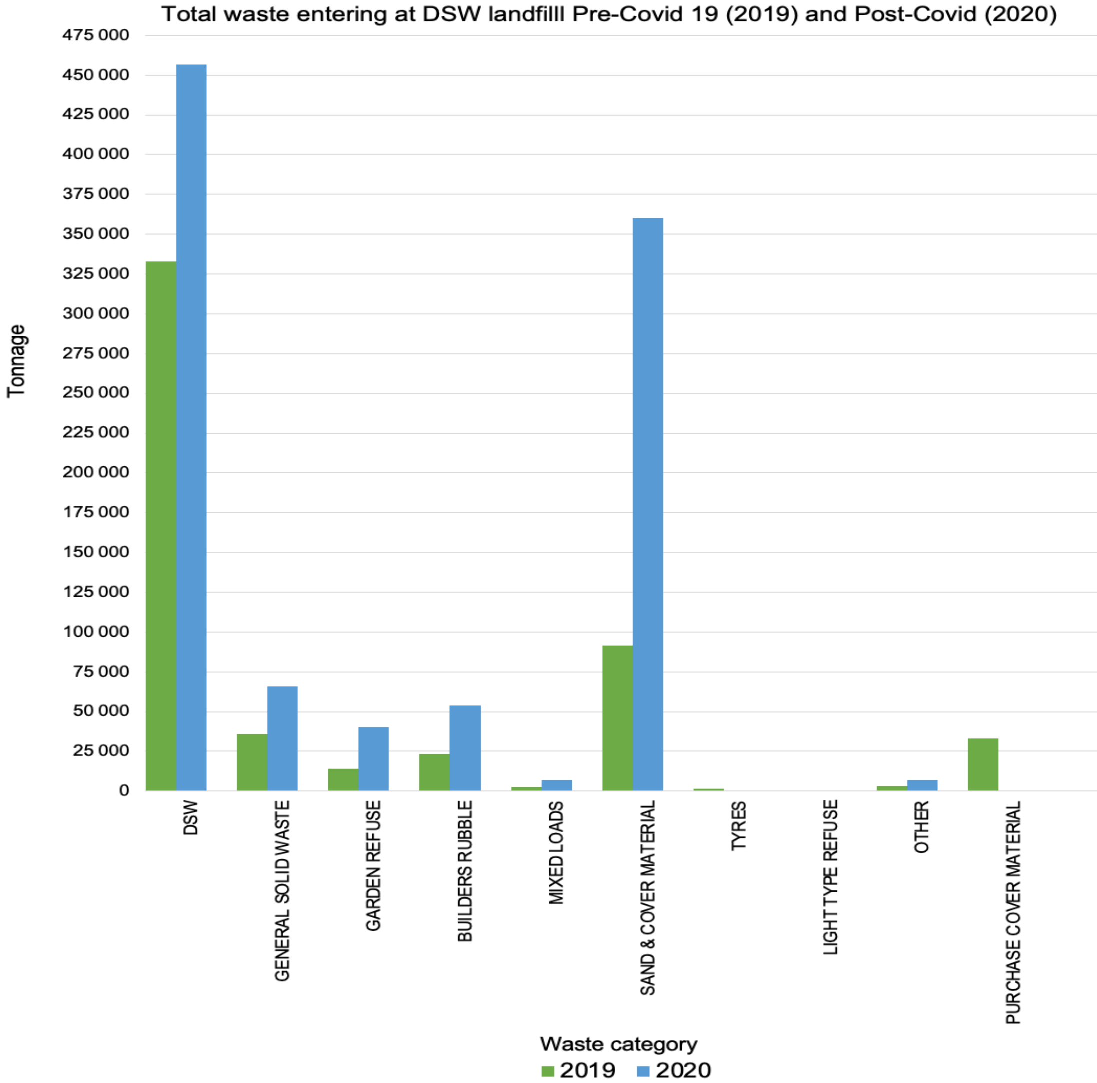

Figure 5.16: Pre Covid-19 versus Post Covid-19 waste at DSW

5.5 WROSE Model Analysis

The Waste Resource Optimisation Scenario Evaluation (WROSE) decision-making tool is used in this research to achieve the aim of establishing the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in eThekwini. The WROSE Model analysis was completed with the various C&D waste scenarios created. Construction and demolition waste mix of builder's rubble, sand and cover material was the waste stream analysed in this study. The WROSE Model analysis was run twice, once using the average tonnage of the last five years for the current analysis. The other iteration was done with a 10 year projection of the waste tonnages. The scenarios and the results are shown below.

Scenario 1: Landfill disposal

Unsorted C&D waste enters landfill and is disposed with no practice of recovery or recycling or reuse. This is typical of not engineered landfills in South Africa. Figure 15.17 shows Scenario 1: Landfill disposal.

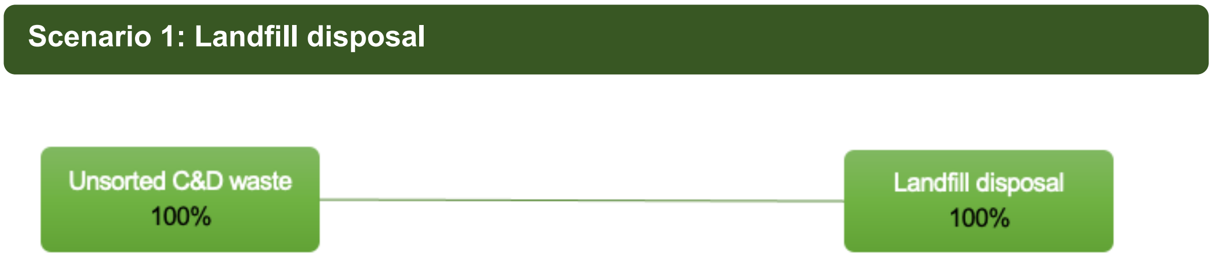

Figure 15.17: Scenario 1: Landfill disposal

Scenario 2: Baseline

Unsorted C&D waste enters DSW landfill and goes through a weighbridge. The waste is then informally sorted by landfill workers into contaminated builders rubble and clean builders rubble. It was assumed that 30 % of the C&D waste that enters the landfill is clean builders rubble. The contaminated builders rubble is disposed into landfill, while clean builders rubble is used for the creation of access roads within landfill. C&D waste in this scenario undergoes no treatment as the builders rubble used in access roads are not crushed or processed. Figure 15.18 shows Scenario 2: Status Quo

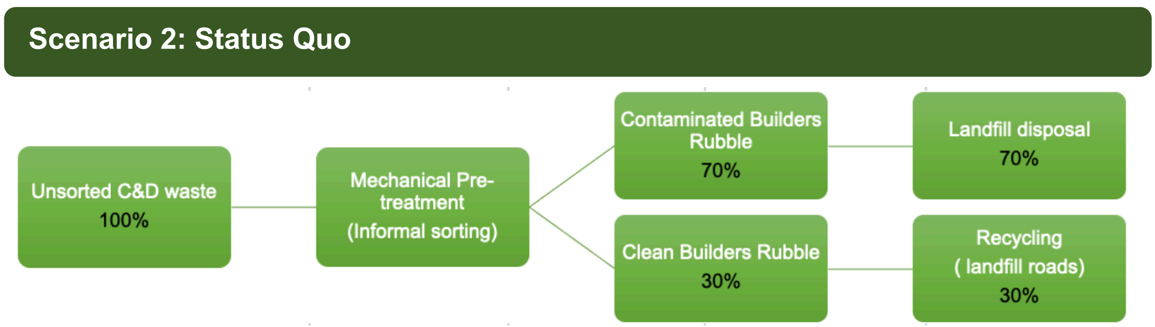

Figure 15.18: Scenario 2: Status Quo

Scenario 3: Recycling

Unsorted C&D waste enters landfill and goes through mechanical pre-treatment of a separation station whereby C&D waste is sorted into contaminated builder rubble and clean builders rubble. It is assumed that 50% of C&D waste that enter the landfill after undergoing sorting and separation will be clean builders rubble. The contaminated builders rubble that contains metals, plastic, wood etc is disposed into landfill. The clean rubble that consists of concrete and masonry is sent through a crusher. The material from the crusher is then recycled as aggregates that is sold/given to the roads department to be used as G5, G4,G7 and crusher sand. Figure 15.19 shows Scenario 3: Recycling.

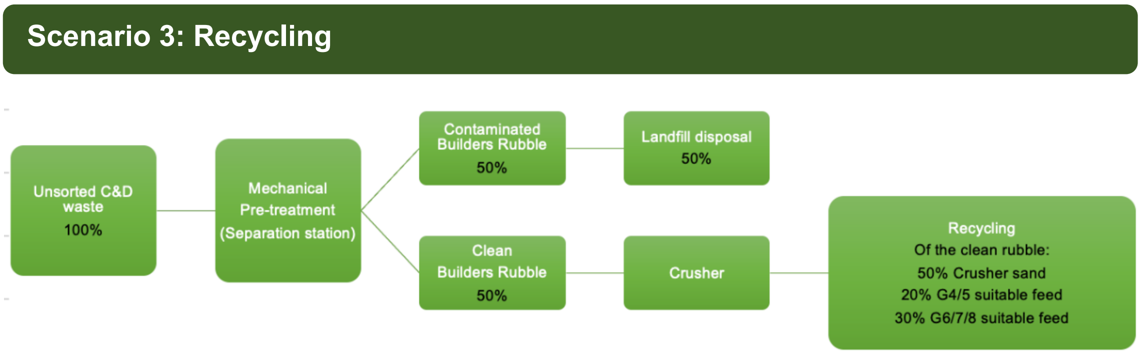

Figure 5.19: Scenario 3: Recycling

Scenario 4: Direct Diversion and Recycling

Unsorted C&D waste enters SandOp Recovery World and DSW Landfills. It is assumed that 50% of the C&D is diverted to SandOp Recovery World and the other 50% enters the landfill and is crushed. Unsorted C&D waste that enters SandOp is placed on a weighbridge, then undergoes a vigorous mechanical pre-treatment with high cost machinery and waste is separated into clean builders rubble and contaminated builders rubble. In SandOp it is assumed that 80% of the waste will be clean builders rubble due to the various sorting mechanisms present. The other 20% of C&D waste, which is contaminated builders rubble, is landfilled. The clean builders rubble is placed through a crusher and the aggregates and fines are used in the creation of concrete which is placed back into the construction industry. At DSW landfills the same procedure as scenario 3. It was assumed that 50% is to be diverted as SandOp Recovery world is located relatively the same distance from Buffelsdraai landfill and is relatively near to former operating landfills such as Bisasar Road and Mariannhill Landfills as seen in Figure 4.14.

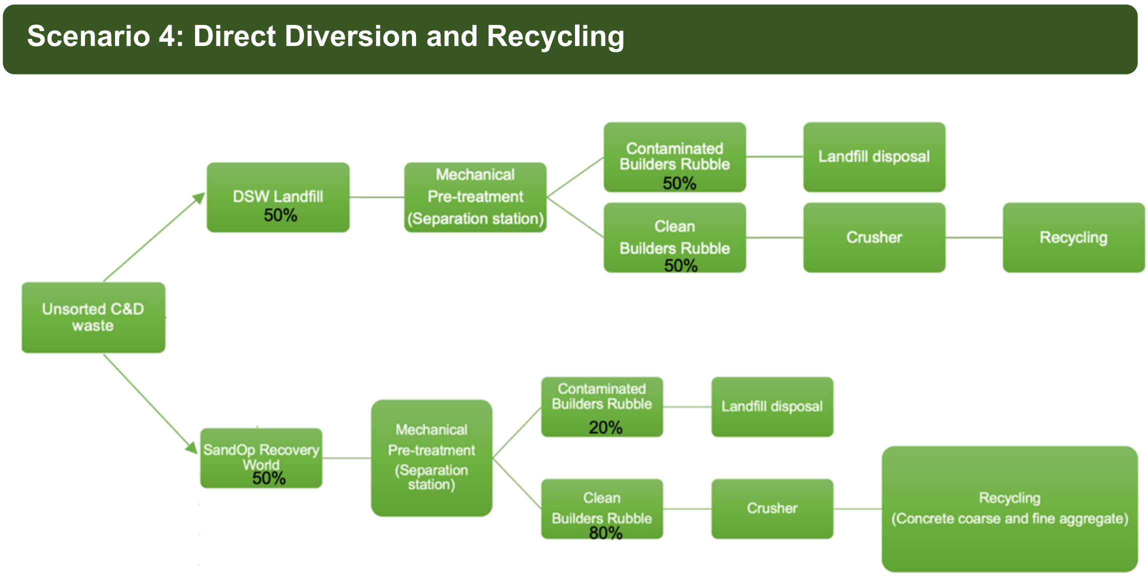

Figure 5.20: Scenario 4: Direct Diversion and Recycling

5.6. 1 Current Landfill airspace savings

One of the most crucial indicators needed by the eThekwini municipality DSW is landfill airspace savings. The landfill airspace savings for the current waste entering the various DSW landfills are shown in Table 5.1 and Figure 5.21 below shows the results from the current landfill airspace savings from the application of the WROSE Model.

Table 5.1: Current Landfill space savings

LANDFILL SITE	BISASAR ROAD	MARIANNHILL	BUFFELSDRAAI	LOVU
SCENARIO	LANDFILL SPACE SAVINGS (m3)			
1	0	0	0	0
2	66967	16570	6854	5405
3	111611	27617	11423	9007,5
4	145095	35903	14850	11710

Figure 5.21 shows the environmental impact of the different scenarios applied to the various landfills in eThekwini. Comparing the scenarios at all four landfills shows that the quantity of C&D waste diverted from landfills increased steadily.

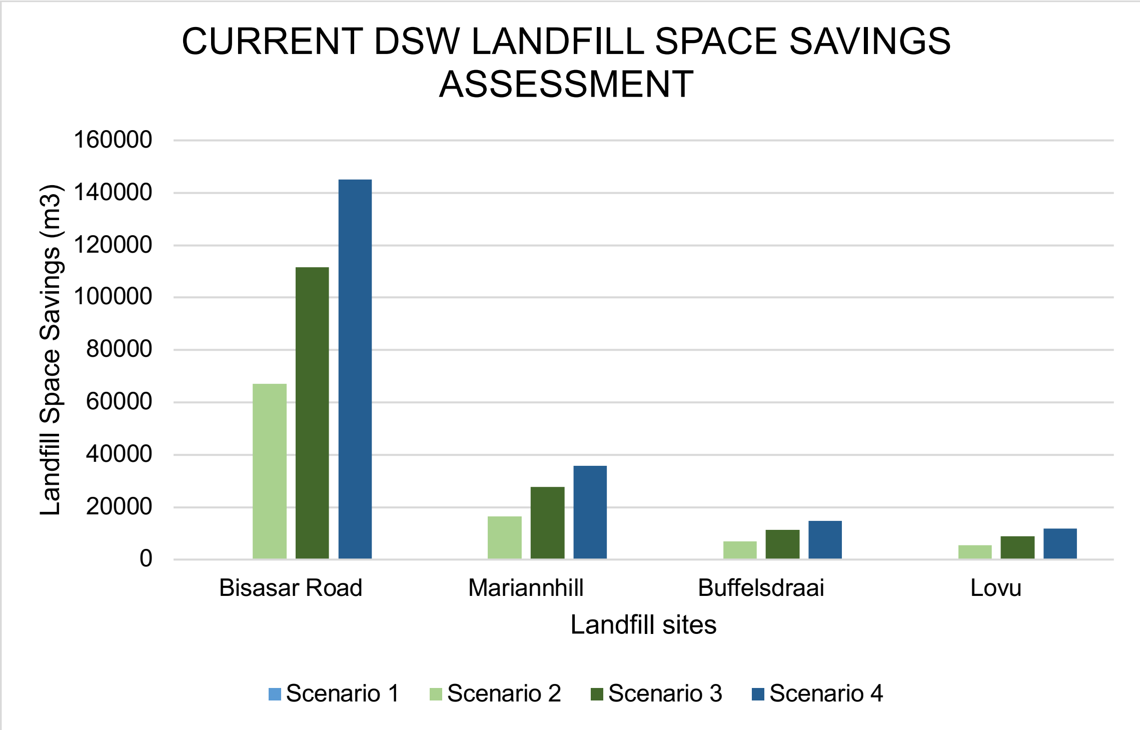

Figure 5.21: Current landfill space savings assessment

Scenario 1, where C&D waste is landfilled, has no landfill space savings and would negatively affect the growing need for more landfill air space in eThekwini. Scenario 2 assumes that 30 % of the C&D waste entering the landfill is used to create roads within the landfill have a positive impact on the environment with a landfill space savings of 600 000 m3 in Bisasar Road landfill. Scenario 3 that contains an on-site crusher at the landfill, has a significant landfill space savings impact. Scenario 4 has the most landfill space savings, and this is due to scenario 4 allowing for diverting C&D waste from entering the landfills.

5.6. 2 Current Job creation potential

The results from the current job creation potential from the application of the WROSE Model are shown in Table 5.2 and the corresponding Figure 5.22.

Table 5.2: Current Job creation potential

LANDFILL SITE	BISASAR ROAD	MARIANNHILL	BUFFELSDRAAI	LOVU
SCENARIO	NUMBER OF JOBS			
1	35	9	4	3
2	36	9	4	3
3	25	6	3	2
4	48	12	6	5

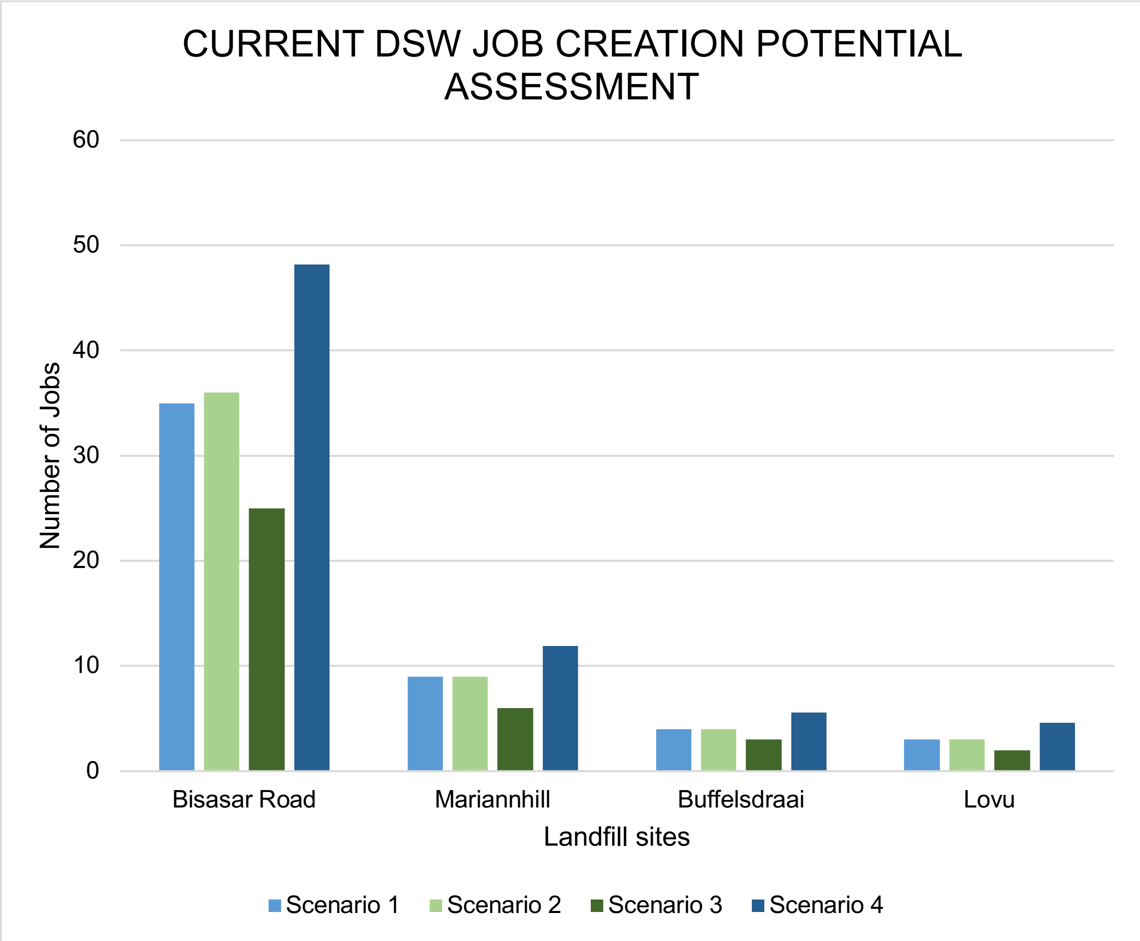

Figure 5.22: Current DSW Job creation potential assessment

Figure 5.22 shows the socio-economic impact of the different scenarios applied to the various landfills in eThekwini. Scenario 4 has the highest socio-economic benefit. All scenarios have a similar job creation potential. Scenario 3 with the operation of a crusher and other machinery does not require as much labour as compared to the other scenarios. Scenario 1 and 2 has a similar amount of job creation as the C&D waste is just double handed in scenario 2 whereby builders rubble is placed on the roads with a rear end loader. The jobs to be created in scenario 3 and 4 would be that of a crusher operator, sorting of C&D waste before crusher, truck drivers, screening, sorting of recycled aggregates and further jobs are created down the life cycle of using recycled aggregates such as laying of the aggregates as subbase, and various other indirect jobs.

5.6. 3 Current economic feasibility

The results from the current economic feasibility of the scenarios from the application of the WROSE Model are shown in Table 5.3 and the corresponding Figure 5.23. The cost shown are the net income of the scenario, hence the negative sign is the loss of money and no sign in front of rand shows a profit when scenario was analysed.

Table 5.3: Current economic feasibility

LANDFILL SITE	BISASAR ROAD	MARIANNHILL	BUFFELSDRAAI	LOVU
SCENARIO	Rand (R)			
1	-R1 757 208	-R434 809	-R179 841	-R141 814
2	-R6 043 081	-R1 495 319	-R618 477	-R487 702
3	R25 029 498	R6 193 377	R2 561 634	R2 019 985
4	R13 767 653	R3 406 711	R1 409 045	R1 111 107

Figure 5.23 shows the economic impact of the different scenarios applied to the various landfills in eThekwini. Scenario 1 and 2 are not economically viable as there is a negative balance in the operations of these scenarios. The municipality has a placed landfill fee of C&D waste to breakeven, as high landfill fees lead to an increase of illegal dumping. Scenario 3 proves to be the most economically feasible. Mariannhill, Buffelsdraai and Lovu landfills show the low economic benefit for scenario 3, this is due to the low quantity of waste, making this scenario not economically viable. Scenario 4 shows a large profit of R13 000 000, benefiting both the public and private sectors. Table 5.3 and Figure 5.23 indicates that scenario 2 is the most expensive scenario with a loss of approximately R 6 000 000 over the past five years. This is evidence that DSW is in a position to apply a new strategy to deal with C&D waste. If a crusher operation had been placed at Bisasar Road Landfill five years ago, DWS would of made approximately R 25 000 000 in profit. This funds could be placed in other waste management sectors that are in need of funding. These results prove that scenario 3 and 4 are economically feasible options for DSW.

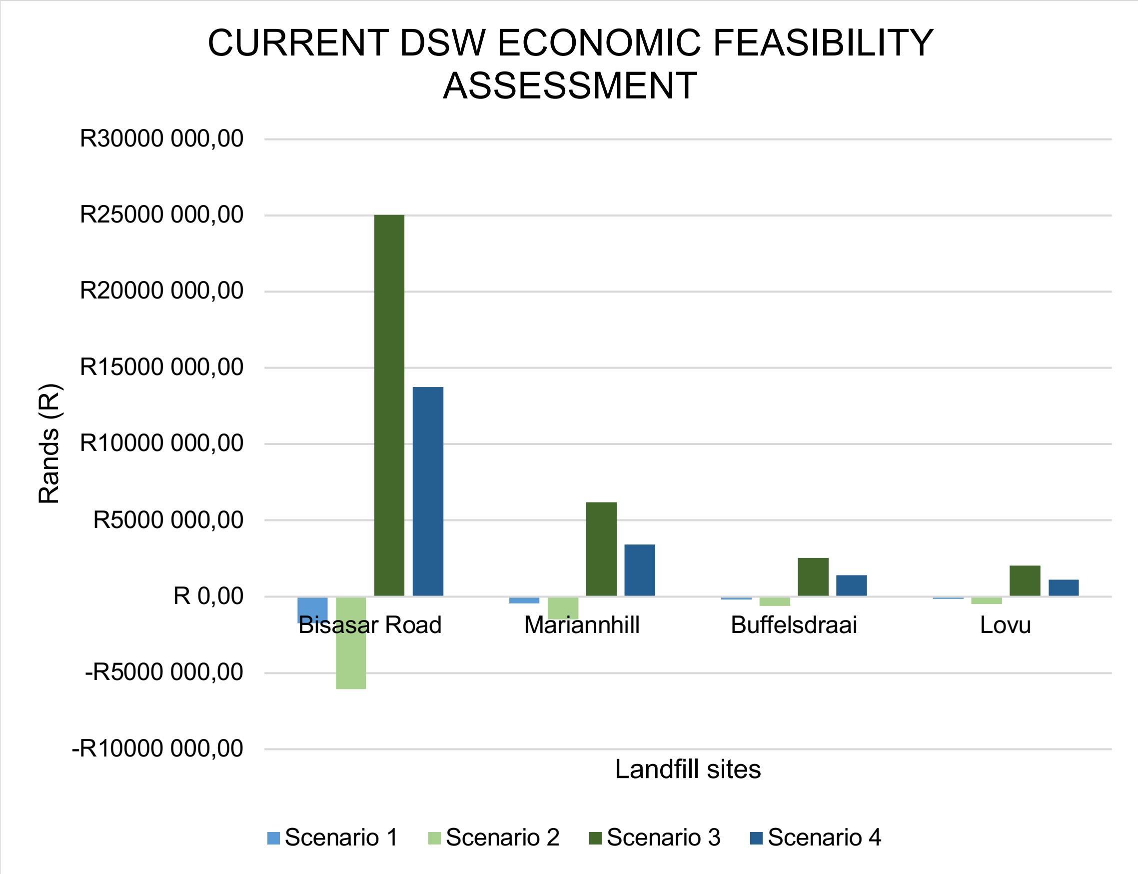

Figure 5.23: Current economic feasibility assessment.

5.6. 4 Projected Landfill space savings

The results from the projected landfill space savings of the scenarios from the application of the WROSE Model are shown in Table 5.4 and the corresponding Figure 5.24. Bisasar Road and Mariannhill landfills are set for closure in 2021, therefore the projected landfill space savings are that of the year 2021. Buffelsdraai and Lovu landfills airspace savings is that of a 10 year projection.

Table 5.4: Projected landfill space savings

LANDFILL SITE	BISASAR ROAD	MARIANNHILL	BUFFELSDRAAI	LOVU
SCENARIO	LANDFILL SPACE SAVINGS (m3)			
1	0	0	0	0
2	60207	10426	314107	494875
3	100345	17376	523512	824791
4	130449	22589	680565	2639331

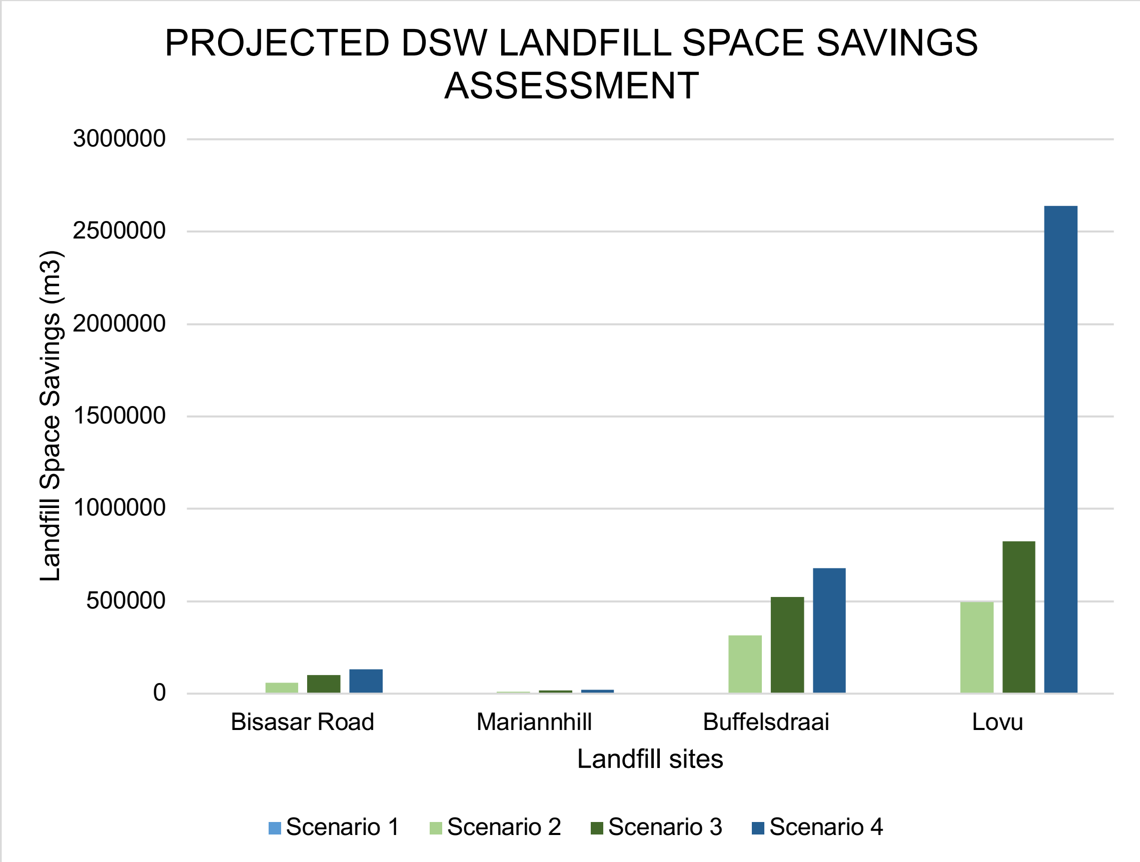

Figure 5.24: Projected landfill space savings assessment

In Figure 5.24, scenario 1 generates the lowest quantity of waste diversion while scenario 4 generates the greatest amount of waste diversion. This is due to the separation of C&D waste, scenarios 1 and 2 assumes no sorting and separation of waste while scenario C&D waste is screened and sorted in scenarios 3 and 4 allowing for greater use of C&D waste therefore generating a higher waste diversion from being landfilled. C&D waste is dense and bulky therefore the diversion of waste from being landfilled will have a positive impact on the landfill airspace. Both scenarios 3 and 4 are preferred for landfill space savings with 2 639 331 m^3 being saved in scenario 4. Based on scenario 4, If a crusher operates at the Lovu landfill, 2 639 331 m^3 of landfill airspace can be saved therefore prolonging the life of the landfill. Lovu Landfill has the highest amount of potential landfill space savings, this is due to large quantities of waste entering Buffelsdraai and Lovu landfills due Bisasar Road and Mariannhill landfills closure.

5.6. 5 Projected Job creation potential

The results from the projected job creation potential from the application of the WROSE Model are shown in Table 5.5 and the corresponding Figure 5.25. Bisasar Road and Mariannhill landfills are set for closure in 2021, therefore the projected landfill space savings are that of the year 2021. Buffelsdraai and lovu landfills airspace savings is that of a 10 year projection.

Table 5.5: Projected job creation potential

LANDFILL SITE	BISASAR ROAD	MARIANNHILL	BUFFELSDRAAI	LOVU
SCENARIO	Number of Jobs			
1	32	5	17	26
2	32	5	17	26
3	22	4	11	18
4	43	8	23	36

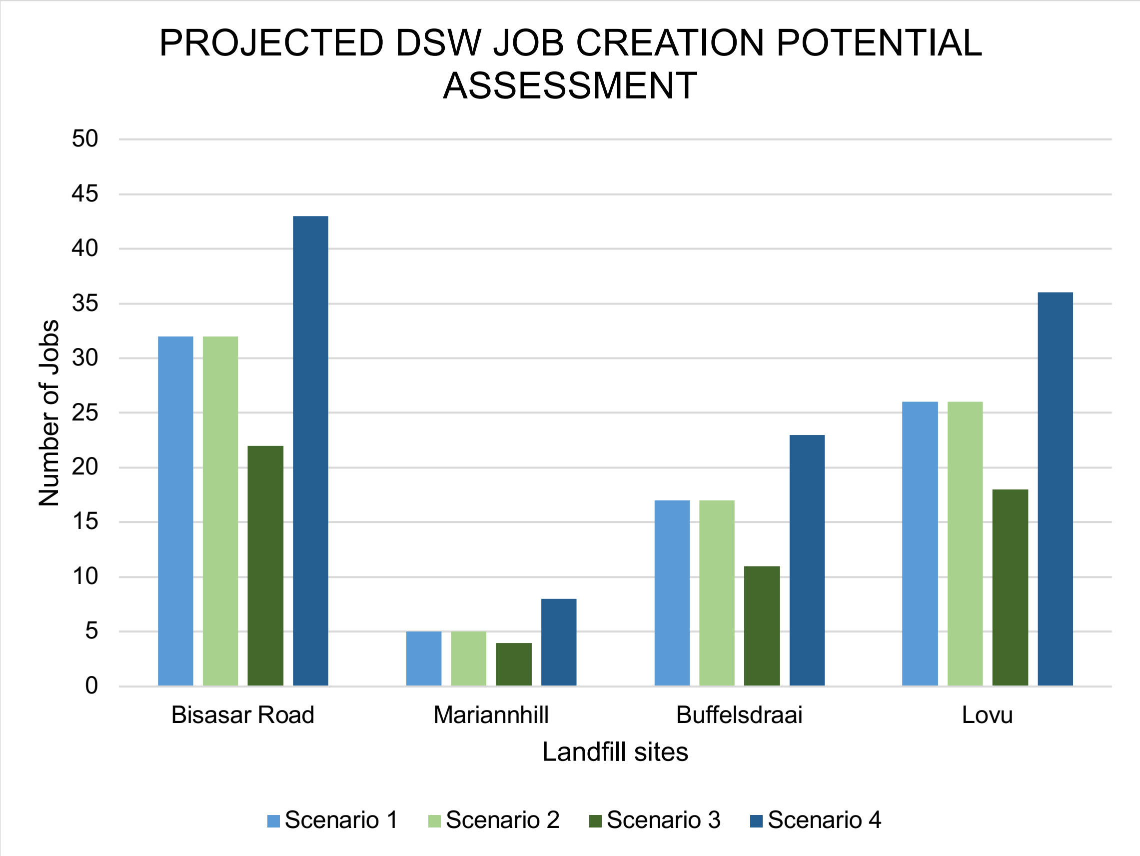

Figure 5.25: Projected job creation potential assessment

The projected job creation potential shows scenario 4 to be the most preferred scenario creating approximately 36 jobs over the next 10 years. Scenario 4 has the highest positive socio-economic impact due to the waste being spread across private and municipal entities, therefore impacting a greater amount of people. Scenario 3 creates the least amount of jobs at the landfill. Scenario 1 and 2 have similar job creation potentials.

5.6. 6 Projected economic feasibility

The results from the 10 year projected economic feasibility of the scenarios from the application of the WROSE Model are shown in Table 5.6 and the corresponding Figure 5.26 Bisasar Road and Mariannhill landfills are set for closure in 2021, therefore the projected landfill space savings are that of the year 2021. Buffelsdraai and Lovu landfills airspace savings is that of a 10 year projection. The cost shown are the net income of the scenario, hence the negative sign is the loss of money and no sign in front of rand shows a profit when scenario was analysed.

Table 5.6: Projected economic feasibility

LANDFILL SITE	BISASAR ROAD	MARIANNHILL	BUFFELSDRAAI	LOVU
SCENARIO	Rand (R)			
1	-R1 579 836	-R273 571	-R8 242 170	-R12 985 508
2	-R5 433 096	-R940 819	-R28 345 026	-R44 657 480
3	R22 503 038	R3 896 728	R117 400 679	R184 964 316
4	R12 377 955	R2 143 422	R64 577 074	R101 740 931

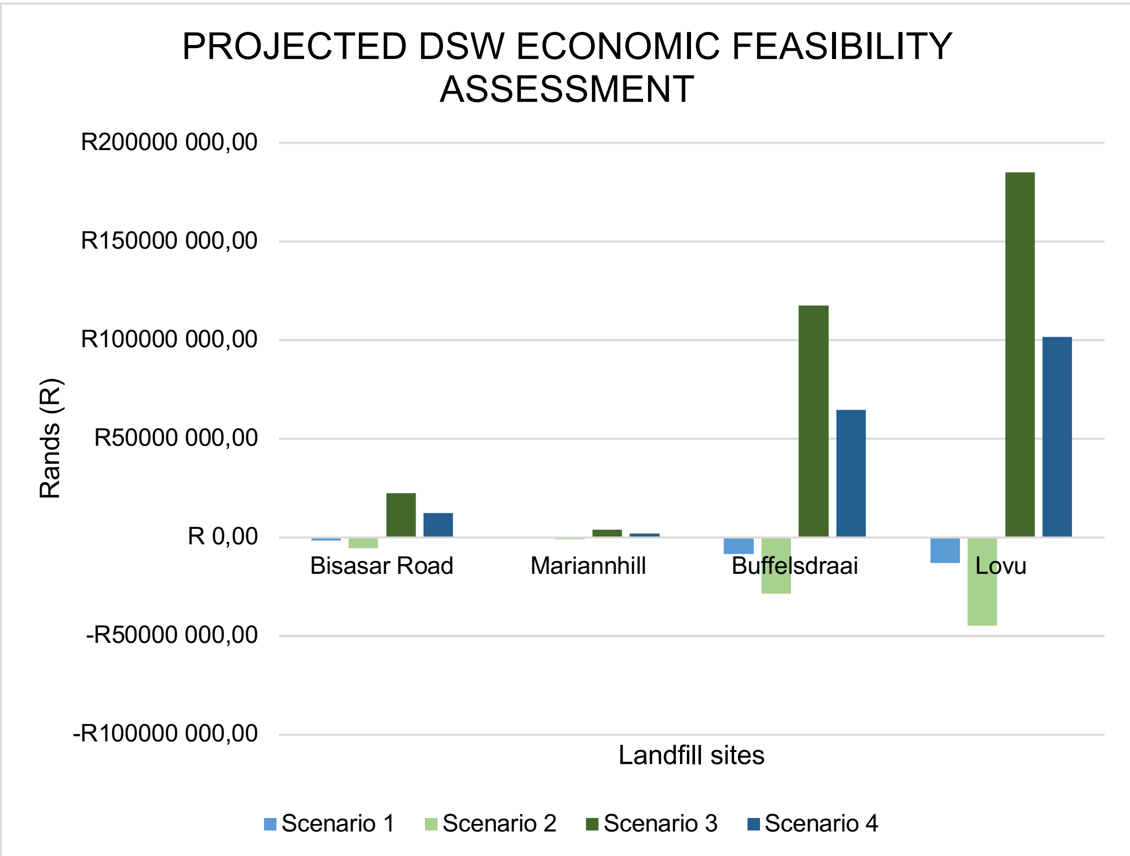

Figure 5.26: Projected economic feasibility assessment

Figure 5.26 shows a significantly high amount of income produced by recycling practices in scenarios 3 and 4. Capital costs of landfilling were excluded in the economic assessment as it was considered that the scenarios use infrastructure that is existing. Scenarios 1 and 2 have an higher cost than revenue from landfill fees therefore requiring a recycling activity to produce income will enable municipality to benefit from such waste rather than unfavourable events. These amounts of income is due to the data being result of a total of 10 year projections.

5.6 Chosen scenario evaluation

Based on the previous graphs, recycling of C&D waste has a positive impact on all the economic, social and environmental indicators analysed. Due to Bisasar Road and Mariannhill landfill closing down in 2021, the waste is to be diverted to both the Buffelsdraai and Lovu landfill. This places immense pressure on the landfills to save crucial landfill airspace. Scenario 4 whereby C&D waste is partly diverted to SandOp Recovery World while a crusher operates at the landfill to generate recycled aggregates for be placed back into the construction industry is presented as the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in the eThekwini Municipality, South Africa. Diverting C&D waste to SandOp Recovery World is an opportunity for the eThekwini municipality to reduce the amount of C&D waste entering landfills hence saving land airspace, reduction of transportation costs for individuals as well as creating employment both in the public and private sectors.

5.7 Chapter summary

This chapter shows the results of the application of the WROSE Model. The results generated were able to allow for the establishment of a the most economical, social and environmentally feasible C&D waste management option.

This research has demonstrated the need for optimization of waste reduction with regards to construction and demolition waste. The weighbridge data analysis reveals that construction and demolition materials such as builders rubble, sand and cover material are the second largest contributor to the overall waste entering DSW landfills. The overall increase rate of builder’s rubble entering DSW landfills is 1000 tons per year. The overall increase rate of sand and cover material entering DSW landfills is 10 800 tons per year. Over the past 20 years, builders rubble peaked at approximately 190 000 tons annually, entering landfills. Sand and cover material once reached a peak of approximately 560 000 ton annually entering landfills. This increase was due construction of the 2010 FIFA World Cup infrastructure. Mariannhill and Bisasar road landfills quantity of C&D waste entering these landfills decreased as the other landfills in Buffelsdraai and Lovu Landfills receiving this waste hence increasing the quantity of C&D waste entering these landfills. The WROSE model analysis of the various four scenarios was completed to achieve the aim of this research, which was to establish the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in eThekwini. The projected waste tonnages show that Lovu landfill would receive the greatest amount of C&D waste.

Scenario 4 was chosen as the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in eThekwini. Scenario 4 whereby Unsorted C&D waste enters SandOp Recovery World and DSW Landfills. The waste that enters DSW and SandOp Recovery World are to be crusher, and the aggregates are to be sold. Scenario 4 displayed the most significant Landfill Space Savings of over 2 600 000 m3 and the most significant Job Creation Potential of 36 jobs at Lovu Landfill. Scenario 3, whereby all unsorted C&D waste enters landfill and undergoes a crushing process to produce recycled masonry and concrete aggregates. The income/savings generated in Scenario 3 at Lovu landfills was that of R184 964 316. Scenario 4 fall behind in the savings. Scenario 1 and 2, where C&D waste is landfilled, displays a loss of approximately R 44 000000 as it costs the municipality more than the landfill tariff to dispose of C&D waste. The municipality aims to break even on the cost of disposing of C&D waste. If tariff increases, there will be a risk of illegal dumping. Therefore, concluding that Scenario 4, proposing a crusher at the Lovu Landfill and diverting a portion of waste to SandOp Recovery World, will be the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in eThekwini.

The latter chapter presents the conclusions and recommendations for this research.

CHAPTER 6

6. CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

The aim of this study was to establish the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in the eThekwini Municipality, South Africa as well as to expand the WROSE model to include the different C&D waste management scenarios. This study aids the eThekwini Municipality to in increasing the landfill airspace and transition towards a circular economy. Recycling of construction and demolition waste can contribute to the national economy while lowering the use of natural resources for construction(Islam et al., 2019). The aim of this research was achieved through the selected methodology of case study and modelling approach. The WROSE Model was utilised and various improvement scenarios were developed to accomplish the aims of this research.

This chapter comprises of a review of the fulfilment of research objectives as well as the conclusion and recommendations for future research.

6.2 Fulfilment of research objectives

The objectives of this research were achieved.

Objective 1:
Review the literature on waste management strategies for C&D waste implemented in South African Municipalities.

Objective 2:
Identify challenges in the sustainable management of C&D waste in the eThekwini Municipality.

Objective 3:
Define and Evaluate WROSE model indicators of sustainability for assessing the waste management scenarios .

Objective 4:
Analyse the eThekwini Municipality as a case study for C&D waste management

Objective 5:
Waste stream analysis at eThekwini municipality using weighbridge data

Objective 6:
Develop improvement scenarios for C&D waste in the WROSE model

Objective 7:
Determine the most feasible scenario upon specific indicators

Objective 1 of reviewing literature was achieved through the completion of a literature review. Objective 2 of identifying the challenges the eThekwini Municipality faces was achieved through an interview with the DSW personnel. Objective 3 of defining and Evaluating WROSE model indicators of was completed in the literature review, where the WROSE Model is discussed in detail. Objective 4 of Analysing the eThekwini Municipality as a case study for C&D waste management was achieved as the eThekwini municipality was used as the case study for this research, hence this research includes an overview of the eThekwini municipality, the characteristics of the DSW landfill sites, and the status quo and challenges faced with C&D waste management within the eThekwini municipality. Objective 5 of a waste stream analysis was completed through a weighbridge data analysis where the data was generated into graphs and critically analysed. Objective 6 of the development of improvement scenarios was accomplished as the proposed scenarios involved the recycling of C&D waste. Objective 7 of determining the most feasible scenario was achieved by completing the WROSE analysis. As a result the most feasible scenario was chosen for the eThekwini municipality and discussed.

6.3 Conclusion and Recommendations

eThekwini Municipality, the third largest municipality in South Africa, has diminishing airspace of its landfills. Construction and demolition waste consumes approximately 40% of eThekwini Municipality's landfill airspace. This study focused on using builders rubble, sand and cover material that enters the DSW landfills as a resource and ultimately diverting waste from being landfilled. Thus this research aimed to establish the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in the eThekwini Municipality and expand the WROSE model to include different C&D waste management scenarios.

To achieve the aims of this study, the economic, social and environmental impacts of each of the proposed scenarios were evaluated, through the use of the WROSE Model. The WROSE model is a decision making tool, that through a Microsoft Excel spreadsheet interface, takes the quantity and quality of the waste and automatically generates the economic, social and environmental impacts such as the Landfill space savings, job creation, greenhouse gas emissions of the waste if it had to undergo different waste management activities such as landfilling, anaerobic digestion and others. The WROSE Model has created various optimization scenarios for various waste streams such as food waste, garden waste, plastic waste and other waste. The WROSE Model had not yet developed a specific waste management strategy for construction and demolition waste and hence did not include C&D waste as in the model. Therefore, this study expanded the WROSE Model to include construction and demolition waste. This expansion involved the development of different waste management activities for C&D waste, such as landfilling, recycling C&D waste by crushing waste at both onsite and off-site locations.

Four proposed C&D waste management scenarios were evaluated using the WROSE Model. Scenario one was landfill disposal where unsorted C&D waste enters the landfill and is disposed of with no practice of recovery or recycling or reuse. Scenario two was the baseline scenario of this study displaying the current activities of DSW landfills. Scenario two is where C&D waste is informally sorted and used to create landfill roads, with little to no treatment of the waste. Scenario three involved onsite recycling, whereby C&D waste is formally sorted and crushed. The material from the crusher is then recycled as aggregates that is sold/given to the roads department to be used as G5, G4,G7 and crusher sand. Scenario four entails direct diversion and recycling of C&D waste. in this scenario, C&D waste enters SandOp Recovery World and DSW Landfills. C&D waste crushed at SandOp Recovery World is converted to high value aggregates due to specialist machinery present.

These four proposed C&D waste management scenarios were then analysed based on the WROSE Model indicators. The analysis consisted of an evaluation of the three pillars of sustainability: the environmental, economic and social impacts of each scenario. Landfill Space Savings, Economic Feasibility and Job creation were the three indicators used in the WROSE Model analysis. All four of eThekwini's landfills (Bisasar Road Landfill, Mariannhill Landfill, Buffelsdraai Landfill and Lovu Landfill) were analysed.

Scenarios two, three and four divert C&D waste from being landfilled. Based on the WROSE Model, by implementing these scenarios, a total of 3 300 000 m^3 of landfill airspace can be saved, 59 jobs created, and R 108 000 000 generated at Buffelsdraai and Lovu landfills over the next ten years. Scenario four was chosen as the most economical, social, and environmentally feasible C&D waste management scenario to be implemented in the eThekwini Municipality. Scenario three can be implemented gradually with the goal of developing into scenario four.

Recycled C&D waste can replace virgin materials and can be used in multiple applications such as aggregate base course(road base), soil stabilisation, pipe bedding and many other applications. Recycling C&D waste may become another source of income for the municipality. A further detailed study of C&D waste that enters DSW landfills is recommended to be complete to understand better the quality of C&D waste entering DSW landfills. An initial small-scale implementation pilot crushing plant should be established at a DSW landfill to ensure the viability of crusher performance. In order to increase South Africa's attention to the social and environmental benefits of reusing and recycling, construction waste incentives and subsidies should be proposed by the government, municipalities and department of labour.

A recommendation of improving specific legislation and regulations, focusing on establishing the mandatory degree of recycling of C&D waste at construction and demolition sites. DSW is recommended to establish a C&D waste policy whereby the C&D waste that enters DSW landfills is classified according to categories: crushed C&D waste, non-crushed C&D waste and heterogenous C&D waste. Landfill tariffs should be altered to these categories, allowing crushed C&D waste to be at low cost and increasing the price on the non-crushed C&D waste and ensure heterogenous C&D waste is priced higher than the other categories. This policy should incentivise the public to separate and crush C&D waste before entering DSW landfills hence saving valuable landfill airspace. This study has addressed certain aims and objectives, but there are many more questions. This research is part of the growing knowledge of optimising waste reduction in the construction sector.

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APPENDICES

Appendix A – Weighbridge and projected data

Weighbridge data

Table A-1 DSW Weighbridge data – Builders Rubble

LANDFILL SITE	BISASAR ROAD	MARIANNHILL	BUFFELSDRAAI	LOVU
YEAR	WASTE RECEIVED (T/ANNUM)			
2001	53486	2944	-	-
2002	48432	3515	-	-
2003	47316	3598	-	-
2004	63018	5244	-	-
2005	78929	8372	-	-
2006	102386	11900	571	-
2007	72438	12136	2526	-
2008	72820	10528	2677	-
2009	155438	10424	11083	-
2010	129758	13143	44259	-
2011	80688	10581	4191	-
2012	88308	15771	9359	-
2013	82505	15206	1936	-
2014	61894	17538	6500	385
2015	66 000	22667	8996	2047
2016	38 830	36003	11317	4636
2017	20 294	37766	25305	3300
2018	28 666	37848	20586	8439
2019	47 215	24103	10115	24557
2020	21364	10602	11133	10685

Table A-2 DSW Weighbridge data – Sand and Cover Material

LANDFILL SITE	BISASAR ROAD	MARIANNHILL	BUFFELSDRAAI	LOVU
YEAR	WASTE RECEIVED (T/ANNUM)			
2001	105555	45278	-	-
2002	174638	26404	-	-
2003	210777	25194	-	-
2004	269090	34464	-	-
2005	340959	40735	-	-
2006	306025	39790	1172	-
2007	380883	47473	752	-
2008	372853	43815	1717	-
2009	485533	26520	4000	-
2010	436077	28224	4030	-
2011	416380	33478	11251	-
2012	497340	49797	10394	-
2013	423796	45930	12514	-
2014	387621	63680	16981	562
2015	276913	55238	18807	3594
2016	383571	51430	30682	6613
2017	332094	73246	34611	5742
2018	352643	81137	23521	44555
2019	47 215	42497	12411	43472
2020	308863	23920	11838	15303

Projected data

Table A-3 Projected tonnages – Builder's Rubble

LANDFILL SITE	BISASAR ROAD	MARIANNHILL	BUFFELSDRAAI	LOVU
YEAR	WASTE RECEIVED (T/ANNUM)			
2015-2020	37062	33798	14575	8944
2021	18098	18579	14802	19761
2022	12680	15838	14869	22850
2023	7261	13097	14936	25938
2024	1842	10355	15004	29026
2025	0	7614	15071	32114
2026	0	4873	15139	35203
2027	0	2131	15206	38291
2028	0	0	15273	41379
2029	0	0	15341	44468
2030	0	0	15408	47556

Table A-4 Projected tonnages – Sand and Cover Material

LANDFILL SITE	BISASAR ROAD	MARIANNHILL	BUFFELSDRAAI	LOVU
YEAR	WASTE RECEIVED (T/ANNUM)			
2015-2020	320095	54578	21978	19880
2021	303007	37025	11912	40673
2022	298122	32011	9034	46614
2023	293237	26997	6155	52555
2024	288353	21983	3277	58496
2025	283468	16968	398	64437
2026	278583	11954	0	70378
2027	273698	6940	0	76319
2028	268814	1926	0	82260
2029	263929	0	0	88201
2030	259044	0	0	94142

Appendix B - WROSE Model Quantities

Table B-1 C&D waste mix - WROSE Model input composition for current tonnages

LANDFILL SITE	BISASAR ROAD
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)
Builders Rubble	37062
Sand & Cover material	320095
Total	357156

LANDFILL SITE	MARIANNHILL
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)
Builders Rubble	33798
Sand & Cover material	54578
Total	88376

LANDFILL SITE	BUFFELSDRAAI
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)
Builders Rubble	14575
Sand & Cover material	21978
Total	36553

LANDFILL SITE	LOVU
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)
Builders Rubble	8944
Sand & Cover material	19880
Total	28824

Table B-2 C&D waste mix - WROSE Model input composition for projected tonnages

LANDFILL SITE	BISASAR ROAD
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)
Builders Rubble	18098
Sand & Cover material	202007
Total	321105

LANDFILL SITE	MARIANNHILL
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)
Builders Rubble	18579
Sand & Cover material	37025
Total	55604

LANDFILL SITE	BUFFELSDRAAI
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)
Builders Rubble	204369
Sand & Cover material	1470869
Total	1675238

LANDFILL SITE	LOVU
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)
Builders Rubble	425076
Sand & Cover material	2214255
Total	2639331

Appendix C - WROSE Model input data (current and projected estimations)

WROSE Model input data Current estimations

Table C-1 Current tonnages WROSE Model input for Scenario 1

LANDFILL SITE	BISASAR ROAD			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	357156			

LANDFILL SITE	MARIANNHILL			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	88376			

LANDFILL SITE	BUFFELSDRAAI			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	36553			

LANDFILL SITE	LOVU			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	28824			

Table C-2 Current tonnages WROSE Model input for Scenario 2

LANDFILL SITE	BISASAR ROAD			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	250009	107147		

LANDFILL SITE	MARIANNHILL			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	61863	26513		

LANDFILL SITE	BUFFELSDRAAI			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	25587	10966		

LANDFILL SITE	LOVU			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	20177	8647		

Table C-3 Current tonnages WROSE Model input for Scenario 3

LANDFILL SITE	BISASAR ROAD			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	178578		178578	

LANDFILL SITE	MARIANNHILL			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	44188		44188	

LANDFILL SITE	BUFFELSDRAAI			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	18277		18277	

LANDFILL SITE	LOVU			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	14412		14412	

Table C-4 Current tonnages WROSE Model input for Scenario 4

LANDFILL SITE	BISASAR ROAD			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	13342			31132

LANDFILL SITE	MARIANNHILL			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	5570			12998

LANDFILL SITE	BUFFELSDRAAI			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	5247			12243

LANDFILL SITE	LOVU			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	3220			7513

WROSE Model input data- Projected estimations

Table C-5 Projected tonnages WROSE Model input for Scenario 1

LANDFILL SITE	BISASAR ROAD			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	321105			

LANDFILL SITE	MARIANNHILL			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	55604			

LANDFILL SITE	BUFFELSDRAAI			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	1675238			

LANDFILL SITE	LOVU			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	2639331			

Table C-6 Projected tonnages WROSE Model input for Scenario 2

LANDFILL SITE	BISASAR ROAD			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	224774	96332		

LANDFILL SITE	MARIANNHILL			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	38923	16681		

LANDFILL SITE	BUFFELSDRAAI			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	1172667	502571		

LANDFILL SITE	LOVU			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	1847532	791799		

Table C-7: Projected tonnages WROSE Model input for Scenario 3

LANDFILL SITE	BISASAR ROAD			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	160553		160553	

LANDFILL SITE	MARIANNHILL			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	27802		27802	

LANDFILL SITE	BUFFELSDRAAI			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	837619		837619	

LANDFILL SITE	LOVU			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	1319666		1319666	

Table C-8 Projected tonnages WROSE Model input for Scenario 4

LANDFILL SITE	BISASAR ROAD			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	112387		80276	128442

LANDFILL SITE	MARIANNHILL			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	19461,4		13901	22241,6

LANDFILL SITE	BUFFELSDRAAI			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	586333		418810	670095

LANDFILL SITE	LOVU			
WASTE FRACTION	QUANTITY OF WASTE DIVERTED (TONNES)			
Strategy	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble Mix	923765,85		659832,75	1055732,4

Appendix D - WROSE Output data

WROSE Output data- Current estimations

Scenario 1

Table D-1 Current -WROSE Model Output for Scenario 1-Bisasar Road Landfill

BISASAR ROAD LANDFILL				
W.R.O.S.E Scenario 1 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	357156			
Bulk Density 1,6 t/m3				
Total Land space saving (m3)	0			
W.R.O.S.E Scenario 1 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Annual Builders Rubble Quantity (tonnes)	357156			
Daily builders Rubble (tonnes)	979			
Jobs per ton	0,036			0,1000
Total job potential	35			
W.R.O.S.E Scenario 1 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Tonnes	357156			
Capital cost				
Operating cost	R 28 572 487			
Revenue	R 26 815 279			
Net	-1757208			

Table D-2 Current -WROSE Model Output for Scenario 1-Mariannhill Landfill

MARIANNHILL LANDFILL				
W.R.O.S.E Scenario 1 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	88376			
Bulk Density 1,6 t/m3				
Total Land space saving (m3)	0			
W.R.O.S.E Scenario 1 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Annual Builders Rubble Quantity (tonnes)	88376			
Daily builders Rubble (tonnes)	242			
Jobs per ton	0,036			
Total job potential	9			
W.R.O.S.E Scenario 1 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Tonnes	88376			
Capital cost				
Operating cost	R 7 070 066			
Revenue	R 6 635 257			
Net	-434809			

Table D-3 Current -WROSE Model Output for Scenario 1-Buffelsdraai Landfill

BUFFELSDRAAI LANDFILL				
W.R.O.S.E Scenario 1 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	36553			
Bulk Density 1,6 t/m3				
Total Land space saving (m3)	0			
W.R.O.S.E Scenario 1 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Annual Builders Rubble Quantity (tonnes)	36553			
Daily builders Rubble (tonnes)	100			
Jobs per ton	0,036			
Total job potential	4			
W.R.O.S.E Scenario 1 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Tonnes	36553			
Capital cost				
Operating cost	R 2 924 240			
Revenue	R 2 744 399			
Net	-179841			

Table D-4 Current -WROSE Model Output for Scenario 1-Lovu Landfill

LOVU LANDFILL				
W.R.O.S.E Scenario 1 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	28824			
Bulk Density 1,6 t/m3				
Total Land space saving (m3)	0			
W.R.O.S.E Scenario 1 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Annual Builders Rubble Quantity (tonnes)	28824			
Daily builders Rubble (tonnes)	79			
Jobs per ton	0,036			
Total job potential	3			
W.R.O.S.E Scenario 1 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Tonnes	28824			
Capital cost				
Operating cost	R 2 305 920			
Revenue	R 2 164 106			
Net	-141814			

Scenario 2

Table D-5 Current -WROSE Model Output for Scenario 2-Bisasar Road Landfill

BISASAR ROAD LANDFILL				
W.R.O.S.E Scenario 2 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	250009	107147		
Bulk Density 1,6 t/m3				
Total Land space saving		66967		
W.R.O.S.E Scenario 2 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	250009	107147		
Daily builders Rubble (tonnes)	685	294		
Jobs per ton	0,036	0,036		
Total job potential	25	11		
W.R.O.S.E Scenario 2 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Tonnes	250009	107147		
Operating cost	R 20 000 741	R 12 857 619		
Revenue	R18 770 696	R 8 044 584		
Net	-1230046	-4813035		

Table D-6 Current -WROSE Model Output for Scenario 2-Mariannhill Landfill

MARIANNHILL LANDFILL				
W.R.O.S.E Scenario 2 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	61863	26513		
Bulk Density 1,6 t/m3				
Total Land space saving		16570		
W.R.O.S.E Scenario 2 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	61863	26513		
Daily builders Rubble (tonnes)	169	73		
Jobs per ton	0,036	0,036		
Total job potential	6	3		
W.R.O.S.E Scenario 2 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Tonnes	61863	26513		
Operating cost	R 4 949 046	R 3 181 530		
Revenue	R 4 644 680	R 1 990 577		
Net	-304366	-1190953		

Table D-7 Current -WROSE Model Output for Scenario 2-Buffelsdraai Landfill

BUFFELSDRAAI LANDFILL				
W.R.O.S.E Scenario 2 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	25587	10966		
Bulk Density 1,6 t/m3				
Total Land space saving		6854		
W.R.O.S.E Scenario 2 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	25587	10966		
Daily builders Rubble (tonnes)	70	30		
Jobs per ton	0,036	0,036		
Total job potential	3	1		
W.R.O.S.E Scenario 2 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Tonnes	25587	10966		
Operating cost	R 2 046 968	R 1 315 908		
Revenue	R 1 921 079	R 823 320		
Net	-125889	-492588		

Table D-8 Current -WROSE Model Output for Scenario 2-Lovu Landfill

LOVU LANDFILL				
W.R.O.S.E Scenario 2 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	20177	8647		
Bulk Density 1,6 t/m3				
Total Land space saving		5405		
W.R.O.S.E Scenario 2 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	20177	8647		
Daily builders Rubble (tonnes)	55	24		
Jobs per ton	0,036	0,036		
Total job potential	2	1		
W.R.O.S.E Scenario 2 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Tonnes	20177	8647		
Operating cost	R 1 614 144	R 1 037 664		
Revenue	R 1 514 874	R 649 232		
Net	-99270	-388432		

Scenario 3

Table D-9 Current -WROSE Model Output for Scenario 3-Bisasar Road Landfill

BISASAR ROAD LANDFILL				
W.R.O.S.E Scenario 3 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	178578		178578	
Bulk Density 1,6 t/m3				
Total Land space saving			111611	
W.R.O.S.E Scenario 3 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	178578		178578	
Daily builders Rubble (tonnes)	489		489	
Jobs per ton	0,036		0,014	
Total job potential	18		7	
W.R.O.S.E Scenario 3 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	178578		178578	
cost	R 14 286 244		R 30 358 268	
revenue	R 13 407 640		R 56 266 371	
net	-878604		25908103	

Table D-10 Current -WROSE Model Output for Scenario 3-Mariannhill Landfill

MARIANNHILL LANDFILL				
W.R.O.S.E Scenario 3 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	44188		44188	
Bulk Density 1,6 t/m3				
Total Land space saving			27617	
W.R.O.S.E Scenario 3 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	44188		44188	
Daily builders Rubble (tonnes)	121		121	
Jobs per ton	0,036		0,014	
Total job potential	4		2	
W.R.O.S.E Scenario 3 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	44188		44188	
cost	R 3 535 033		R 7 511 945	
revenue	R 3 317 628		R 13 922 727	
net	-217405		6410782	

Table D-11 Current -WROSE Model Output for Scenario 3-Buffelsdraai Landfill

BUFFELSDRAAI LANDFILL				
W.R.O.S.E Scenario 3 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	18277		18277	
Bulk Density 1,6 t/m3				
Total Land space saving			11423	
W.R.O.S.E Scenario 3 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	18277		18277	
Daily builders Rubble (tonnes)	50		50	
Jobs per ton	0,036		0,014	
Total job potential	2		1	
W.R.O.S.E Scenario 3 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	18277		18277	
cost	R 1 462 120		R 3 107 005	
revenue	R 1 372 200		R 5 758 560	
net	-89920		2651555	

Table D-12 Current -WROSE Model Output for Scenario 3-Lovu Landfill

LOVU LANDFILL				
W.R.O.S.E Scenario 3 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	14412		14412	
Bulk Density 1,6 t/m3				
Total Land space saving			9008	
W.R.O.S.E Scenario 3 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	14412		14412	
Daily builders Rubble (tonnes)	39		39	
Jobs per ton	0,036		0,014	
Total job potential	1		1	
W.R.O.S.E Scenario 3 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	14412		14412	
cost	R 1 152 960		R 2 450 040	
revenue	R 1 082 053		R 4 540 933	
net	-70907		2090893	

Scenario 4

Table D-13 Current -WROSE Model Output for Scenario 4-Bisasar Road Landfill

BISASAR ROAD LANDFILL				
W.R.O.S.E Scenario 4 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	125005		89289	142862
Bulk Density 1,6 t/m3				
Total Land space saving	0		55806	89289
W.R.O.S.E Scenario 4 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	125005		89289	142862
Daily builders Rubble (tonnes)	342		245	391
Jobs per ton	0,036		0,014	0,083
Total job potential	12,319		3	32
W.R.O.S.E Scenario 4 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	125005		89289	142862
cost	R10 000 371		R 15 179 134	R 28 572 487
revenue	R 9 385 348		R 28 133 185	R 30 001 112
net	-615023		12954051	1428624

Table D-14 Current -WROSE Model Output for Scenario 4-Mariannhill Landfill

MARIANNHILL LANDFILL				
W.R.O.S.E Scenario 4 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	30932		22094	35350
Bulk Density 1,6 t/m3				
Total Land space saving	0		13809	22094
W.R.O.S.E Scenario 4 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	30932		22094	35350
Daily builders Rubble (tonnes)	85		61	97
Jobs per ton	0,036		0,014	0,083
Total job potential	3		1	8
W.R.O.S.E Scenario 4 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	30932		22094	35350
cost	R 2 474 523		R 3 755 973	R 7 070 066
revenue	R 2 322 340		R 6 961 364	R 7 423 569
net	-152183		3205391	353503

Table D-15 Current -WROSE Model Output for Scenario 4-Buffelsdraai Landfill

BUFFELSDRAAI LANDFILL				
W.R.O.S.E Scenario 4 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	12794		9138	14621
Bulk Density 1,6 t/m3				
Total Land space saving	0		5711	9138
W.R.O.S.E Scenario 4 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	12794		9138	14621
Daily builders Rubble (tonnes)	35		25	40
Jobs per ton	0,036		0,014	0,083
Total job potential	1		1	3
W.R.O.S.E Scenario 4 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	12794		9138	14621
cost	R 1 023 484		R 1 553 503	R 2 924 240
revenue	R 960 540		R 2 879 280	R 3 070 452
net	-62944		1325777	146212

Table D-16 Current -WROSE Model Output for Scenario 4-LovuLandfill

LOVU LANDFILL				
W.R.O.S.E Scenario 4 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	10088		7206	11530
Bulk Density 1,6 t/m3				
Total Land space saving	0		4504	7206
W.R.O.S.E Scenario 4 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	10088		7206	11530
Daily builders Rubble (tonnes)	28		20	32
Jobs per ton	0,036		0,014	0,083
Total job potential	1		1	3
W.R.O.S.E Scenario 4 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	10088		7206	11530
cost	R 807 072		R 1 225 020	R 2 305 920
revenue	R757 437		R 2 270 466	R 2 421 216
net	-49635		1045446	115296

WROSE Output data- Projected estimations

Scenario 1

Table D-17 Projected -WROSE Model Output for Scenario 1-Bisasar Road Landfill

BISASAR ROAD LANDFILL				
W.R.O.S.E Scenario 1 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	321105			
Bulk Density 1,6 t/m3				
Total Land space saving	0			
W.R.O.S.E Scenario 1 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Annual Builders Rubble Quantity (tonnes)	321105			
Daily builders Rubble (tonnes)	880			
Jobs per ton	0,036			0,1000
Total job potential	32			
W.R.O.S.E Scenario 1 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
tons/year	321105			
cost	R 25 688 400			
revenue	R 24 108 563			
net	-1579837			

Table D-18 Projected -WROSE Model Output for Scenario 1-Mariannhill Landfill

MARIANNHILL LANDFILL				
W.R.O.S.E Scenario 1 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	55604			
Bulk Density 1,6 t/m3				
Total Land space saving	0			
W.R.O.S.E Scenario 1 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Annual Builders Rubble Quantity (tonnes)	55604			
Daily builders Rubble (tonnes)	152			
Jobs per ton	0,036			
Total job potential	5			
W.R.O.S.E Scenario 1 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
tons/year	55604			
cost	R 4 448 320			
revenue	R 4 174 748			
net	-273572			

Table D-19 Projected -WROSE Model Output for Scenario 1-Buffelsdraai Landfill

BUFFELSDRAAI LANDFILL				
W.R.O.S.E Scenario 1 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	1675238			
Bulk Density 1,6 t/m3				
Total Land space saving	0			
W.R.O.S.E Scenario 1 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Annual Builders Rubble Quantity (tonnes)	167524			
Daily builders Rubble (tonnes)	459			
Jobs per ton	0,036			
Total job potential	17			
W.R.O.S.E Scenario 1 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
tons/year	1675238			
cost	R 134 019 040			
revenue	R 125 776 869			
net	-8242171			

Table D-20 Projected -WROSE Model Output for Scenario 1-Lovu Landfill

LOVU LANDFILL				
W.R.O.S.E Scenario 1 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	2639331			
Bulk Density 1,6 t/m3				
Total Land space saving	0			
W.R.O.S.E Scenario 1 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
Annual Builders Rubble Quantity (tonnes)	263933			
Daily builders Rubble (tonnes)	723			
Jobs per ton	0,036			
Total job potential	26			
W.R.O.S.E Scenario 1 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 Crusher at DSW	Recycling Type 3 Crusher at SandOp
tons/year	2639331			
cost	R 211 146 480			
revenue	R 198 160 971			
net	-12985509			

Scenario 2

Table D-21 Projected -WROSE Model Output for Scenario 2-Bisasar Road Landfill

BISASAR ROAD LANDFILL				
W.R.O.S.E Scenario 2 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	224774	96332		
Bulk Density 1,6 t/m3				
Total Land space saving		60207		
W.R.O.S.E Scenario 2 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	224774	96332		
Daily builders Rubble (tonnes)	616	264		
Jobs per ton	0,036	0,036		
Total job potential	22	9		
W.R.O.S.E Scenario 2 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	224774	96332		
cost	R 17 981 880	R 11 559 780		
revenue	R 16 875 994	R 7 232 569		
net	-1105886	-4327211		

Table D-22 Projected -WROSE Model Output for Scenario 2-Mariannhill Landfill

MARIANNHILL LANDFILL				
W.R.O.S.E Scenario 2 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	38923	16681		
Bulk Density 1,6 t/m3				
Total Land space saving		10426		
W.R.O.S.E Scenario 2 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	38923	16681		
Daily builders Rubble (tonnes)	107	46		
Jobs per ton	0,036	0,036		
Total job potential	4	2		
W.R.O.S.E Scenario 2 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	38923	16681		
cost	R 3 113 824	R 2 001 744		
revenue	R 2 922 324	R 1 252 424		
net	-191500	-749320		

Table D-23 Current -WROSE Model Output for Scenario 2-Buffelsdraai Landfill

BUFFELSDRAAI LANDFILL				
W.R.O.S.E Scenario 2 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	1172667	502571		
Bulk Density 1,6 t/m3				
Total Land space saving		314107		
W.R.O.S.E Scenario 2 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	117267	50257		
Daily builders Rubble (tonnes)	321	138		
Jobs per ton	0,036	0,036		
Total job potential	12	5		
W.R.O.S.E Scenario 2 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	1172667	502571		
cost	R93 813 328	R60 308 568		
revenue	R88 043 808	R37 733 061		
net	-5769520	-22575507		

Table D-24 Projected -WROSE Model Output for Scenario 2-Lovu Landfill

LOVU LANDFILL				
W.R.O.S.E Scenario 2 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	1847532	791799		
Bulk Density 1,6 t/m3				
Total Land space saving		494875		
W.R.O.S.E Scenario 2 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	184753	79180		
Daily builders Rubble (tonnes)	506	217		
Jobs per ton	0,036	0,036		
Total job potential	18	8		
W.R.O.S.E Scenario 2 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	1847532	791799		
cost	R 147 802 536	R95 015 916		
revenue	R 138 712 680	R59 448 291		
net	-9089856	-35567625		

Scenario 3

Table D-25 Projected -WROSE Model Output for Scenario 3-Bisasar Road Landfill

BISASAR ROAD LANDFILL				
W.R.O.S.E Scenario 3 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	160553		160553	
Bulk Density 1,6 t/m3				
Total Land space saving			100345	
W.R.O.S.E Scenario 3 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	160553		160553	
Daily builders Rubble (tonnes)	440		440	
Jobs per ton	0,036		0,014	
Total job potential	16		6	
W.R.O.S.E Scenario 3 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	160553		160553	
cost	R 12 844 200		R 27 293 925	
revenue	R 12 054 282		R 50 586 882	
net	-789918		23292957	

Table D-26 Projected -WROSE Model Output for Scenario 3-Mariannhill Landfill

MARIANNHILL LANDFILL				
W.R.O.S.E Scenario 3 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	27802		27802	
Bulk Density 1,6 t/m3				
Total Land space saving			17376	
W.R.O.S.E Scenario 3 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	27802		27802	
Daily builders Rubble (tonnes)	76		76	
Jobs per ton	0,036		0,014	
Total job potential	3		1	
W.R.O.S.E Scenario 3 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	27802		27802	
cost	R 2 224 160		R 4 726 340	
revenue	R 2 087 374		R 8 759 854	
net	-136786		4033514	

Table D-27 Projected -WROSE Model Output for Scenario 3-Buffelsdraai Landfill

BUFFELSDRAAI LANDFILL				
W.R.O.S.E Scenario 3 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	837619		837619	
Bulk Density 1,6 t/m3				
Total Land space saving			523512	
W.R.O.S.E Scenario 3 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	83762		83762	
Daily builders Rubble (tonnes)	229		229	
Jobs per ton	0,036		0,014	
Total job potential	8		3	
W.R.O.S.E Scenario 3 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	837619		837619	
cost	R67 009 520		R 142 395 230	
revenue	R62 888 435		R 263 916 995	
net	-4121085		121521765	

Table D-28 Projected -WROSE Model Output for Scenario 3-Lovu Landfill

LOVU LANDFILL				
W.R.O.S.E Scenario 3 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	1319666		1319666	
Bulk Density 1,6 t/m3				
Total Land space saving			824791	
W.R.O.S.E Scenario 3 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	131967		131967	
Daily builders Rubble (tonnes)	362		362	
Jobs per ton	0,036		0,014	
Total job potential	13		5	
W.R.O.S.E Scenario 3 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	1319666		1319666	
cost	R105 573 240		R224 343 135	
revenue	R 99 080 486		R415 800 206	
net	-6492754		191457071	

Scenario 4

Table D-29 Projected -WROSE Model Output for Scenario 4-Bisasar Road Landfill

BISASAR ROAD LANDFILL				
W.R.O.S.E Scenario 4 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	112387		80276	128442
Bulk Density 1,6 t/m3				
Total Land space saving	0		50173	80276
W.R.O.S.E Scenario 4 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	112387		80276	128442
Daily builders Rubble (tonnes)	308		220	352
Jobs per ton	0,036		0,014	0,083
Total job potential	11,076		3	29
W.R.O.S.E Scenario 4 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	112387		80276	128442
cost	R 8 990 940		R13 646 963	R25688 400
revenue	R 8 437 997		R25 293 441	R26 972 820
net	-552943		11646478	1284420

Table D-30 Projected -WROSE Model Output for Scenario 4-Mariannhill Landfill

MARIANNHILL LANDFILL				
W.R.O.S.E Scenario 4 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	19461		13901	22242
Bulk Density 1,6 t/m3				
Total Land space saving	0		8688	13901
W.R.O.S.E Scenario 4 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	19461		13901	22242
Daily builders Rubble (tonnes)	53		38	61
Jobs per ton	0,036		0,014	0,083
Total job potential	2		1	5
W.R.O.S.E Scenario 4 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	19461		13901	22242
cost	R 1 556 912		R 2 363 170	R 4 448 320
revenue	R 1 461 162		R 4 379 927	R 4 670 736
net	-95750		2016757	222416

Table D-31 Projected -WROSE Model Output for Scenario 4-Buffelsdraai Landfill

BUFFELSDRAAI LANDFILL				
W.R.O.S.E Scenario 4 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	586333		418810	670095
Bulk Density 1,6 t/m3				
Total Land space saving	0		261756	418810
W.R.O.S.E Scenario 4 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	58633		41881	67010
Daily builders Rubble (tonnes)	161		115	184
Jobs per ton	0,036		0,014	0,083
Total job potential	6		2	15
W.R.O.S.E Scenario 4 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	586333		418810	670095
cost	R46 906 664		R 71 197 615	R134 019 040
revenue	R44 021 904		R131 958 497	R140 719 992
net	-2884760		60760882	6700952

Table D-32 Projected -WROSE Model Output for Scenario 4-LovuLandfill

LOVU LANDFILL				
W.R.O.S.E Scenario 4 (Landfill Space- saving)- Indicator 1				
Waste fraction	Quantity of waste diverted (Tonnes)			
Waste fraction	Landfill Disposal	Recycling Type 1 No crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Builders Rubble	923766		659833	1055732
Bulk Density 1,6 t/m3				
Total Land space saving	0		412395	659833
W.R.O.S.E Scenario 4 (Job creation)- Indicator 2				
	strategy			
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
Annual Builders Rubble Quantity (tonnes)	92377		65983	105573
Daily builders Rubble (tonnes)	253		181	289
Jobs per ton	0,036		0,014	0,083
Total job potential	9		3	24
W.R.O.S.E Scenario 4 (Economic Feasibility)- Indicator 3				
	Landfill disposal	Recycling Type 1 No Crusher	Recycling Type 2 crusher	Recycling Type 3 SandOp Operations
tons/year	923766		659833	1055732
cost	R73 901 268		R112 171 568	R211 146 480
revenue	R69 356 340		R207 900 103	R221 703 804
net	-4544928		95728535	10557324

Appendix E - WROSE Model assumptions

Aggregate volume assumptions

VOLUME ASSUMPTIONS		
Assume 1m^3 = 1 ton		
SEPARATION / SCREENING Description : new material coming in over the weighbridge. Keep like materials in separate piles for further processing or sale e.g. Asphalt, sand, clay, stone, concrete, pavers, bricks etc.	Assuming: The breakdown of above incoming material is approximately – 50%, Sand/fines 30% Mixed (brick, mortar, paving) 20% Concrete slabs/ lintels/ boulders	(CityOfCapeTown, 2018)
CRUSHING Description : crushing coarse material (rubble, concrete, bricks, boulders etc) into crushed stone. The crushed material should be properly graded into G4/5 and/or G7/8, for onward sale.	Assuming: Incoming mixed material consists of approximately – 50% Crushable material and 50% Contaminated material	(CityOfCapeTown, 2018)
<u>DSW:</u>	50% crushable material consisting of: 20% G4/5 suitable feed 30% G6/7/8 suitable feed	CityOfCapeTown, 2018)
<u>SandOp Recovery World:</u>	50% crushable material consisting of: 50% Concrete aggregate 50% Fine aggregate	SandOp Personnel

	According to SandOp classification: 25% A Class aggregates 25% B Class aggregates 50% C Class aggregates *This variation is largely dependent on the waste that enters SandOp	

Costing assumptions

COSTING ASSUMPTIONS		
SALE OF PRODUCTS		
DSW:		
G4/5	R 150 m^3	(SandCo, 2020)
G6/7	R 175 m^3	(SandCo, 2020)
Building Sand	R 315 m^3	(SandCo, 2020)
SandOp Recovery World:		
A Class	R 200 m^3	(Sandop, 2020)
B Class	R 110 m^3	(Sandop, 2020)
C Class	R 100 m^3	(Sandop, 2020)
LANDFILL TARIFF		
DSW:		
Tariff for mixed builders rubble	R 75,08	DSW Personnel
SandOp Recovery World:		
Tariff for mixed builders rubble	R 60,00	(Sandop, 2020)
OPERATIONAL COST		
DSW:		
Landfill disposal (Single handling of waste)	R 80 per ton	DSW Personnel
Recycling Type 1 (Double handling of waste) Creation of landfill roads	R 120 per ton	DSW Personnel
Recycling Type 2 Crusher at DSW Landfill	R 170 per ton	Atomic demolishers Personnel BROS recycling
SandOp Recovery World: Crusher at SandOp	R 250 per ton	SandOp Personnel
DENSITY		
Bulk density	1.6 t/m^3	(IWMSA, 2018)

Job creation assumptions

JOB CREATION ASSUMPTIONS		
EQUATION	$\frac{tons\ of\ waste\ per\ day}{number\ of\ employees} = x\ tons\ of\ waste\ per\ job$	(Kisoon and trois, 2019)
DSW:	Number of employees - 98,5 Tons of waste per day : 2736.9 tons of waste per day 1 employee =27,8 tons of waste Therefore 0,036	
SandOp Recovery World:	Number of employees – 25 Tons of waste per day : 300 tons of waste per day 1 employee = 12 tons of waste Therefore 0,083	(Sandop, 2020)
Atomic demolishers:	Number of employees – 7 Tons of waste per day : 500 tons of waste per day 1 employee = 72 tons of waste Therefore 0,014	Atomic demolishers Personnel