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Sustainable Waste Management: A Decision Support Framework

by

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Engineering at Stellenbosch University

Supervisor: K. von Leipzig

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Declaration

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Abstract

Sustainable Waste Management: A Decision Support Framework

T.I de Beer

Thesis: MScEng

March 2013

The aim of this thesis is to address the need for sustainable development within waste management. It explores how sustainability can be assessed and used as the basis for high level decision making within waste management. Stellenbosch University (SU) was used as a case study to demonstrate how information can be gathered and used for decision support.

The literature reviewed, showed a wide area of focus within which sustainability is defined and how businesses and organisations shift towards a model of corporate responsibility. The concept of sustainability was then presented within waste management. Life Cycle Assessment (LCA) and Multi-Criteria Decision Analysis (MCDA), were presented as management tools that could facilitate the assessment and decision making process within a sustainable waste management framework.

The two management tools, Sustainable Life Cycle Analysis (SLCA) and Analytical Hierarchal Process (AHP) (branches of LCA and MCDA respectively), were used to develop a framework to be applied to SU Waste Management System. By integrating the two tools, a framework was established that could measure the sustainability of current waste management practices and provide a decision support tool. The framework was validated by applying it to the Stellenbosch University waste system. The framework that was developed delivered a set of sustainable results from which decision makers could base policy decisions. The framework then facilitated the decision making process and a sustainable waste management policy was selected.

The application modelled the decision makers preferences and resulted in a policy being selected which favoured high levels of recycling and waste prevention. The results represented an approach which, when compared to the current practice, was more expensive but more environmentally friendly and socially acceptable. The findings provide an exciting basis for future research, where decisions are based on sustainable principles. The framework has potential to be expanded into other areas of management and is not limited to a university environment.

Uittreksel

Volhoubare Afvalbestuur: ’n Besluitneemings Raamwerk

(“Sustainable Waste Management: A Decision Support Framework”)

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Die doel van hierdie tesis is om die behoefte aan volhoubare ontwikkeling binne afvalbestuur aan te spreek. Die tesis ondersoek hoe die volhoubaarheid in afvalbestuur bepaal kan word, en hoe dit dan gebruik kan word as basis vir beleid besluitneming binne afvalbestuur. Die Universiteit Stellenbosch (US) is as ’n gevallestudie gebruik om te demonstreer hoe inligting versamel kan word en as ondersteuning vir beleidbesluitneming gebruik kan word.

Die literatuurstudie dek ’n wye veld waarbinne daar op volhoubaarheid gefokus word. Dit wys ook hoe maatskappye en organisasies na ’n model van korporatiewe verantwoordelikheid beweeg. Die konsep van volhoubaarheid word dan binne die mileu van afvalbestuur aangebied. Die Lewenssiklus Assesering (LSA) en Multi-Kriteria Besluitnemings Analise (MKBA) wat gebruik is, kan dien as bestuur hulpmiddel om die assessering van, en besluitneming binne ’n volhoubare afvalbestuur te vergemaklik.

Vanuit die twee hulpmiddels, is Volhoubare Lewens Siklus Analise (VLSA) en Analitiese Hierargiese Proses (AHP), gebruik om ’n raamwerk te ontwikkel wat toegepas is op die US. Deur die twee hulpmiddels te integreer kan ’n raamwerk geskep word wat die volhoubaarheid van die huidige afvalbestuur praktyke en wat kan dien as ‘n ondersteunende hulpmiddel met die besluitnemingsprosesse. Die waardasie van die raamwerk wat ontwikkel was, het ‘n stel volhoubare resultate opgelewer, wat besluitnemers gebruik het om hul beleidsbesluite op te baseer.

Die besluitnemers se voorkeure is gebaseer op die bevindinge van die VLSA en het bepaal watter beleid gekies is. Die bevindinge het 'n duurder, maar meer omgewingsvriendelike en sosiaal aanvaarbare beleid verteenwoordig. Hierdie bevindinge bied 'n opwindende basis vir toekomstige navorsingwerk, waar besluitneming op volhoubare beginsels gebaseer is. Die raamwerk het potensiaal vir uitbreiding na ander gebiede van bestuur en is nie beperk tot 'n universiteitsomgewing nie.

Acknowledgements

I would like to express my sincere gratitude to the following people and organisations:

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The Author
March, 2013

Dedications

I would like to dedicate this thesis to my family for their continuous love and support.

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Acronyms

AHP	Analytical Hierarchal Process
AP	Acidification Potential
BEE	Black Economic Empowerment
CI	Confidence Interval
CR	Consistency Ratio
CBA	Cost Benefit Analysis
DM	Decision Maker
DEAT	Department of Environmental Affairs and Tourism
DTI	Department of Trade and Industry
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EU	European Union
EP	Eutrophication Potential
GRI	Global Reporting Initiative
GWP	Global Warming Potential
GHG	Green House Gasses
IWMS	Integrated Waste Management System
IWM	Integrated Waste Management
ISWM	Integrated Sustainable Waste Management

ISO	International Standards Organization
JSE	Johannesburg Stock Exchange
LCA	Life Cycle Analysis
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCIA	Life Cycle Impact Assessment
MAUT	Multi-Attribute Utility Theory
MEC	Minister of the Executive Council
MCA	Multi-Criteria Analysis
MCDA	Multi-Criteria Decision Analysis
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NPV	Net Present Value
NWMS	National Waste Management Strategy
PV	Present Value
RI	Random Index
RSA	Republic of South Africa
S-LCA	Social Life Cycle Assessment
SETAC	Society of Environmental Toxicology and Chemistry
SU	Stellenbosch University
SIGMA	Sustainability-Integrated Guidelines for Management
SLCA	Sustainable Life Cycle Analysis
SD	Sustainable Development
UNEP	United Nations Environmental Programme
UNFP	United Nations Food Programme

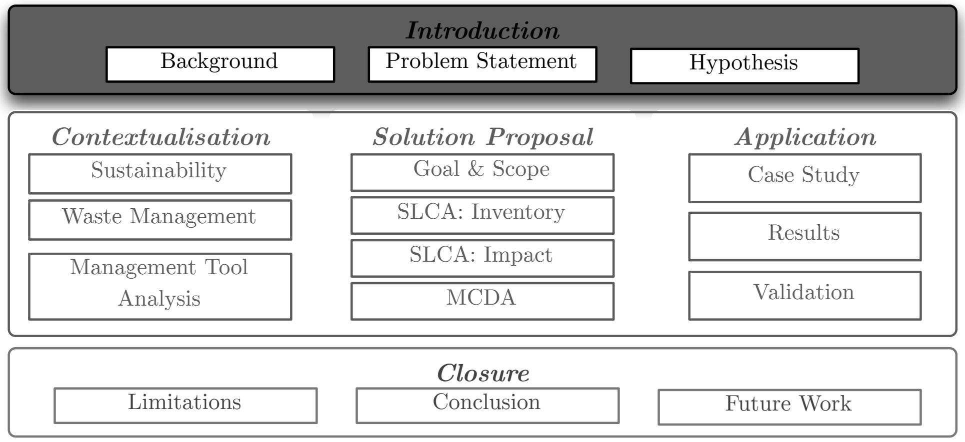
WIS	Waste Information Systems
WISARD	Waste Integrated System Assessment for Recovery and Disposal
WMS	Waste Management System
WARM	Waste Reduction Model
WCED	World Commission on The Environment and Development

Chapter 1

Introduction

Chapter Aim:

The aim of this chapter is to introduce the core concepts that will be used throughout the thesis. A clear problem statement and hypothesis is then framed. Thereafter, the research design is established that will attempt to address the stated research objective.



Chapter Outcomes:

⇒ ***Exploration*** of research domain.
⇒ ***Definition*** of research problem and hypothesis.
⇒ ***Design*** of research study.
⇒ ***Designation*** of document structure.

1.1 Introduction

For many people, products just appear in a shop, they are bought, consumed and then disappear into a black box named waste. This happens with very little awareness of how the product was made and the impact it has, however small, on nature, the society and the economy. Sustainable development requires more than just evolving technologies or enhancements to cost-benefit analysis. It requires a paradigm shift in the way in which humans see the world. We exist within a web of connections and we cannot separate the impacts of actions into separate compartments (Giddings *et al.*, 2002).

With an ever growing population, and ever increasing economy, the waste being produced by South Africa is increasing rapidly. In 1997 it was estimated that around 42 million tons was sent to landfills, and it was predicted that by the year 2010, nearly 70 million tons would go to landfills (National Treasury, 2011). The fundamentals of waste prevention, avoidance, minimisation, reuse and recycling for sustainable development, have been incorporated, in South African waste legislation (Government of South Africa, 2009b). Effective waste management can provide improved employment, potential and economic empowerment, through product reuse and recycling (Spamer, 2009).

Sustainability has thus become an imperative in every aspect of people's lives. Waste management is no exception. The need for waste management which takes into account the needs of sustainable development, is gaining momentum. This is why the need for a sustainable solid waste management system has become crucial. With an ever increasing call for waste management solutions, solid waste systems need to be economically viable, socially acceptable and environmentally friendly.

Sustainable solutions to man-made problems have become the focus of many international organisations in recent years. The issue of waste has also not been left behind in this regard. The need for sustainable solutions to South Africa's ever growing mountain of waste, has become a prominent issue with regard to legislation and governance. The latest information regarding waste in South Africa, was generated in 1997 (DEAT, 2006). This results in strategies and policies being formed without the correct or current base of information. A lack of information is thus a stumbling block in national policy decision making.

1.2 Background of this Study

The study aims to construct a decision support framework for waste management at SU. This section will provide an overview of waste and sustainability. It will initially focus on the international obligations countries face, then move to the current South African scene and finally a brief look will be given of SU.

1.2.1 International Obligations

The United Nations Conference on Environmental Development, or the "Earth Summit", was hosted by Rio de Janeiro in 1992. The conference was the first of its kind to promote a global programme for sustainable development and the result was Agenda 21. Agenda 21 was wholly adopted by the United Nations. It sets out a thorough plan of action which is to be implemented by its member governments and organisations (United Nations, 1992).

Ten years later, at the Earth Summit 2002, the United Nations reaffirmed its full commitment to the implementation of the programme. Agenda 21 consists of four sections and forty chapters, which deals with the full spectrum of sustainability topics. Chapter 21, of the Agenda specifically deals with the management of solid waste. The chapter begins with an emphasis on the environmental impact of waste and the importance of the effective and efficient management thereof (United Nations, 1992). The chapter also identifies four major programme goals, which lead to effective waste management. They were identified as:

- minimising waste,
- increasing the amount of waste reused and recycled,
- the promotion of environmentally sound waste disposal and
- the extension of waste management services.

It is suggested, that the above programme goals are interrelated and should be integrated in a holistic municipal waste management framework, in which "all sectors of society should participate" (United Nations, 1992). For each of the four programme goals, several objectives and activities are specified:

i. to stabilise and reduce waste for final disposal;

ii. to implement procedures;

iii. to assess the quantity and composition of wastes development and implementation of environmentally sound technologies;

iv. to reduce waste by monitoring changes in waste quantities and quality promotion of public education; and

v. to cooperate, with relevant stakeholders, in minimising waste through reuse and recycling.

Disposing of waste requires policies and frameworks that promote the sustainable management of waste. The needs of developed countries, and those of developing countries, are very different (United Nations, 1992). Therefore, different factors and solutions need to be considered when constructing and applying waste management solutions to different countries. Waste management in South Africa must thus be considered unique with its own set of factors and needs.

1.2.2 Waste Generators in South Africa

The purpose of the South African Government, with regard to waste management, is to prevent ecological degradation, prevent pollution and secure a sustainable growth path, as noted by Ginindza (2012). The measures that have been put in place "seek to prevent the amount of waste generated and, where it is generated, to ensure that waste is: reused, recycled and recovered in an environmentally sound manner before being disposed of" (Government of South Africa, 2007).

The National Waste Act tries to ensure that generators of waste comply with certain generic roles, functions and responsibilities. The generators must comply with the following, as stipulated by the Government of South Africa (2000):

- Familiarising and complying with applicable legislation and regulations.
- Keeping records of the quantities and types of general and hazardous waste generated.
- Managing waste such that there is no threat to the environment and public health.
- Exploring clean technology, resource recovery and recycling, in order to minimise waste generation.
- Hazardous waste generators must be registered with the Department of Environmental Affairs and Tourism (DEAT), when the waste information system database for the registration of waste generators is in place.

- Providing the best qualitative and quantitative baseline information required by local authorities, consultants and planners.
- Ensuring that waste storage areas meet appropriate regulations and by-laws and make adequate provision for projected waste generation.
- Compiling plans to ensure that adequate and appropriate provision is made for the management of current and projected waste streams.

Organisations that generate waste, need to have systems that include the management of any waste generated. The Government of South Africa (2007) states that waste management includes “measures” and the “avoidance of generating waste” wherever possible. Sushil (1990) defines waste management as:

> *a multi-disciplinary activity which involves engineering principles, urban and regional planning, management techniques and social sciences to economically minimise the overall waste produced by a system under consideration.*

In South Africa, the responsibilities of a waste producer mainly include the need to limit the damage to the environment and human health. As a waste producer, SU is therefore compelled to enhance its own waste management practices to conform to or even improve upon the provisions stipulated by Government.

1.2.3 Stellenbosch University

Stellenbosch is South Africa’s second oldest town and is host to Stellenbosch University. The University is recognised as one of the top four universities in South Africa. The history of the University can be traced back to the 1800’s, when the then Victoria College was started as a seminary school. The University officially gained its independent status in 1914, and Stellenbosch University was then officially established (Stellenbosch University, 2011*a*).

The University has ten faculties, of which eight - AgriSciences, Arts and Social Sciences, Education, Engineering, Law, Science, Theology and the larger part of Economic and Management Sciences - are located on the main campus in Stellenbosch. Stellenbosch campus is situated in the heart of the Cape Winelands as can be seen in Figure 1.1. The faculty of Health Sciences is situated on the Tygerberg campus. Bellville Park campus is home to the Business School and the school’s Executive Development programme. The coastal town of Saldanah serves as the base for the

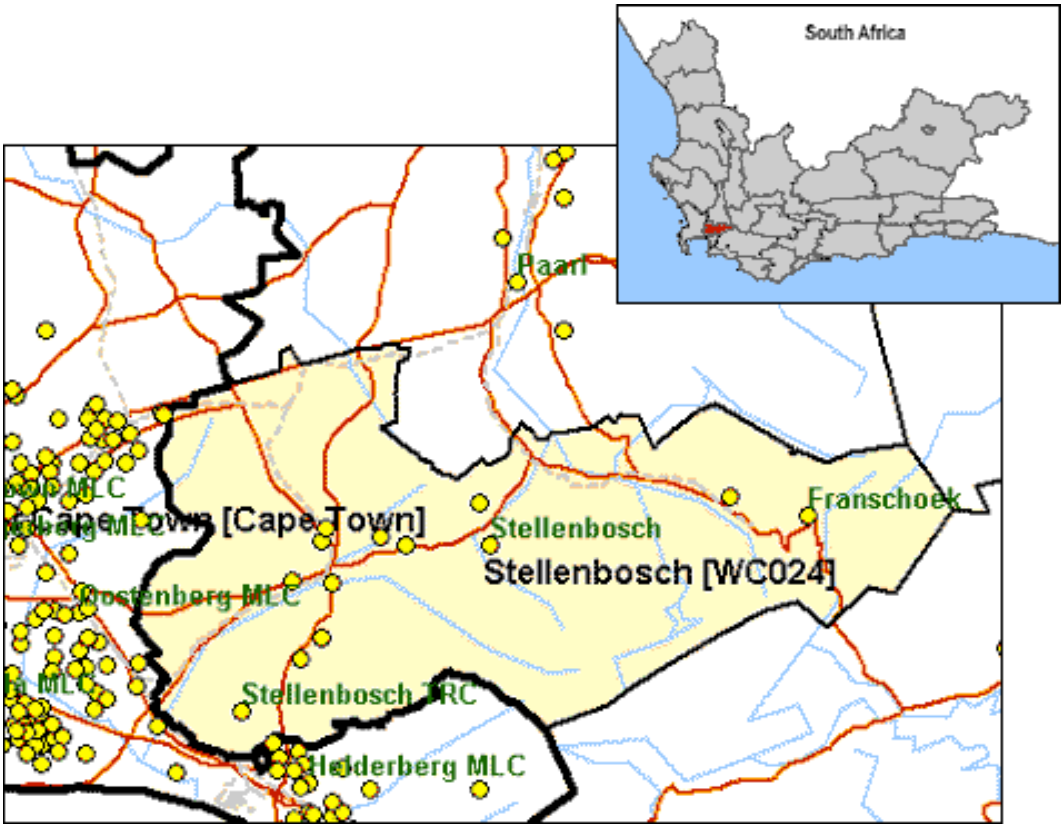


Figure 1.1: A map of the Municipal area of Stellenbosch (The Western Cape Government, 2010)

Faculty of Military Sciences (Stellenbosch University, 2011*a*).

The main campus currently caters for more than 25000 students and staff. Of these students, 5000 live on campus, in student housing. The University has four types of buildings, where waste is collected (Stellenbosch University, 2011*b*).

- Administrative Buildings and Support Services (36 buildings)
- Sporting Facilities (19 buildings)
- Academic Buildings (44 buildings)
- Residences and University Houses (28 residences and 51 houses)

The entire town of Stellenbosch has an estimated population of 58 000 (Stellenbosch Municipality, 2011). The footprint of the University's main campus is therefore vast and can have a major impact on the people, the environment and economy of the town and the surrounding region. Waste management is an integral part of keeping the town and University clean and accounts for large budgetary and environmental effects. The thesis therefore, focuses on the waste management and incorporating sustainability into every part of decision making.

1.3 Research Domain

Sustainability, waste management and decision making are the three spheres of the research domain addressed in this thesis. The solution space for this thesis is therefore the intersection of all three spheres, as represented in Figure 1.2.

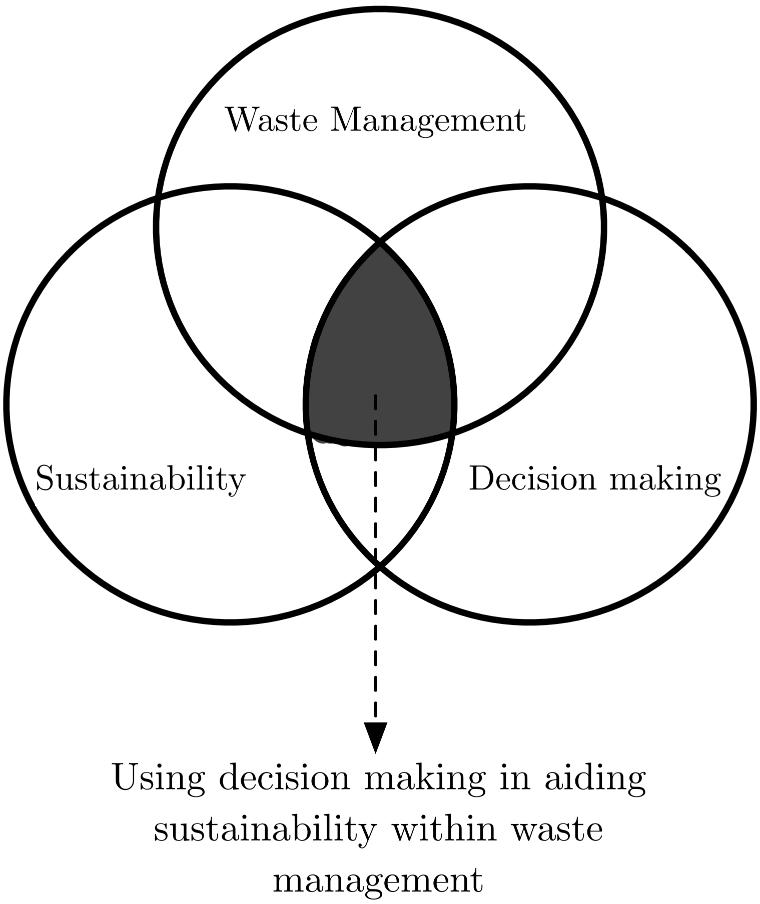


Figure 1.2: Research Domain.

1.3.1 Sustainability

The term sustainability has become a word which is used in a diverse range of contexts and situations. Completing a search for the word in google there are more than 300 different definitions. The definitions of which are applied to a wide variation of topics and applications.

For the purpose of this thesis, sustainability requires the synthesis of the environmental objectives, social equity and economic demands - the three pillars of sustainability. In this research project the three pillars are ingrained in the waste management decision making.

1.3.2 Waste Management

Waste management in this study refers to the management of Municipal Solid Waste (MSW) and not other liquid, gaseous and radioactive waste materials. Solid waste includes all materials, products and items discarded by society when no longer needed or regarded as useless, as well as organic substances such as plant and animal rests from household and commercial activity. For the purpose of this study it refers specifically to the waste which is produced by Stellenbosch University.

The management of waste can consist of a variety of different stages. There are generally four components: storage, collection, processing and disposal.

1.3.3 Decision Making

Decision making is the primary function of management. It guides and controls the process allowing a system and organisation to function properly. Decision making must allow for the proper context, goal and information to be taken into account.

Many different decision support aids have been created that seek to organise and manage the way decisions are made at every level within a business. Peter Drucker, states that making good decisions is a crucial skill, required by every organisation. In the fields of waste management and sustainability, there are multiple objectives and criteria that have to be taken into consideration. The need for effective high level decision making is thus crucial.

1.4 Problem Statement

The body of knowledge concerning the management of waste and sustainability is constantly growing. However, gaps remain evident when connecting the two domains. Sustainable management deals with the three pillars of the: environment, economy and society. Initial research has indicated that Life Cycle Assessment (LCA) and Multi-Criteria Decision Analysis (MCDA) are two tools that can be used to improve the sustainable management of waste systems.

The motivation for this thesis is based on a number of different arguments. Corporate responsibility is shifting away from only loyalty to the shareholder, but to being a good corporate citizen. Sustainability within waste management is therefore a necessary step in the evolution of a business and its operations (King, 2009). Sustainability is a complex field with multiple facets that need to be firstly assessed and then decided upon. Waste management is also an intricate field that relates to multiple stakeholders and role players.

In light of the complex requirements of sustainability and waste management, the aim of this thesis is to investigate and then develop a management framework using LCA and MCDA. The framework will enable the assessment and decision support required for a sustainable WMS. LCA and MCDA will seek to address the following shortcomings identified in the field of sustainability and waste management:

i. Lack of information regarding sustainability when making decisions on waste management.

ii. The impacts of waste management on the three pillars of sustainability.

iii. The large number of factors and objectives that must be taken into account for implementing a sustainable waste management system.

This therefore leads to the primary research question:

> ***Can LCA and MCDA be used to improve the sustainable management of a waste system?***

The question leads to the null hypothesis:

> H_0***: A framework based on LCA and MCDA is not able to improve the sustainable management of a waste system.***

1.5 Research Design and Methodology

This section clarifies the research methods to be used and the objectives that form part of this thesis.

1.5.1 Research Design

The research design is the blueprint or plan of how research is to be conducted. Mouton (2001) refers to three different classifications of research design: qualitative, quantitative and mixed methods. Studies can rarely ever be classified as one or the other. Therefore they can be described as being more qualitatively or quantitatively inclined.

A mixed methods approach is used as a basis for the research design that leans towards a quantitative approach. The design will attempt to address the proposed research question and objectives.

1.5.2 Research Methodology

The methodology will be structured in a manner to provide a logical and insightful answer to the research question posed in Section 1.4.

Figure 1.3, describes the research methodology followed in this thesis. In Chapter 1 the problem statement is described and the hypothesis is formulated. An exhaustive literature study is then undertaken, in order to properly contextualise the prob-

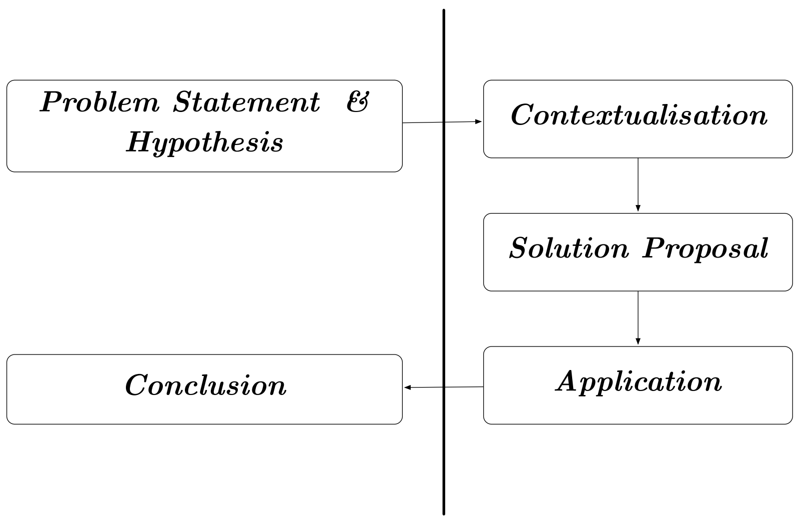


Figure 1.3: Research methodology

lem and thus provide perspective on possible solutions. A proposed solution is then created using the reviewed literature. The solution will provide a framework to be applied to a real world case study. The solution will then be tested, by applying it to a real world case study. The results of the case study are to be analysed with regard to the parameters set out in the proposed solution. Finally, the concluding chapter seeks to integrate the four elements of the above methodology and conclude the thesis.

1.5.3 Research Objectives

The research outcomes of this thesis are constructed based on a series of research objectives. The objectives will be created in order to test the null hypothesis. The thesis is divided into an ordered set of objectives that are represented in Table 1.1. The objectives will be addressed according to respective chapters.

Table 1.1: Research Objectives

Contextualizition	*Chapter 2* 1. Contextualise sustainability and its application to organisations. 2. Provide a holistic understanding of waste management with respect to sustainability. 3. Identify tools to support sustainable waste management. *Chapter 3* 4. Investigate management tools in detail. 5. Select tools that can be applied to a sustainabile and waste management framework.
Solution Proposal	*Chapter 4* 6. Construct a framework that can be used to assess and provide decision support based on sustainability .
Application	*Chapter 5* 7. Apply the framework constructed to an applicable case study. 8. Assess the framework outputs. 9. Validate the analysed results.

The first research objective, contextualisation, establishes a theoretical basis and thereby creates a foundation for the rest of the study. Chapter 2 includes an exhaustive literature review that provides a rigorous understanding of sustainability and waste management. Chapter 3 explores the tools that are usable in managing waste in a sustainable manner.

A solution is then proposed. The proposal will draw upon the findings of the literature review. It will then address the objective of developing a sustainable assessment and decision making framework for waste management, using LCA and MCDA.

The application of the proposed solution involves three research objectives. The first is the application of the framework developed on a case study. The second, aims to assess the results from the case study. And lastly, the results the framework must be validated.

1.6 Document Structure

The document structure addresses the needs of the research objectives and corresponds to the stated research design.

Chapter 1: Introduction
Chapter 1 describes the complexities and need for sustainable solutions. There is also a distinct need for sustainable solutions to managing waste, as it effects society, the natural environment and the economy. New research is constantly required to assess and improve current waste management practices and align them to sustainable principles.

Chapter 2: Sustainability and Waste Management
Chapter 2 presents a literary study and contextualises the problem. The fundamentals of sustainability and waste management are illustrated, along with an outline of current management tools that are used to support sustainable decision making within waste management.

Chapter 3: The Necessary Management Tools
Chapter 3 provides an in-depth analysis of management tools that were briefly covered in Chapter 2. The analysis conducted, outlines how and what management tools are used in waste management and sustainability.

Chapter 4: Building a Sustainable Framework

Using the tools reviewed in Chapter 3, Chapter 4 aims to create a framework that is able to assess sustainability and aid in sustainable decision making. The chapter also outlines the framework procedure.

Chapter 5: Case Study - Stellenbosch University

Chapter 5 applies the framework developed in a real life case study to an organisation in South Africa. The results are examined and presented. The framework and the results are then validated.

Chapter 6: Conclusion

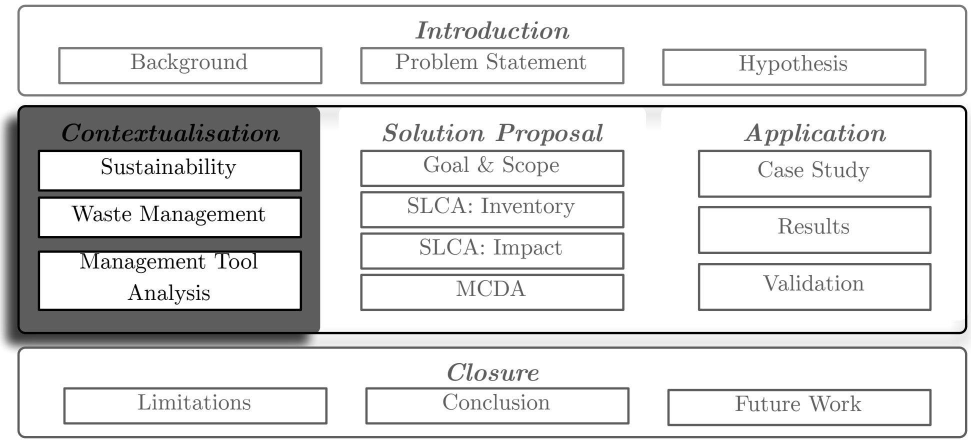
Chapter 6 reviews the research that was conducted. The chapter provides the limitations of the study that was conducted and of the framework that was constructed. The final conclusions are made that either confirm or dispel the null hypothesis stated in Chapter 1. Lastly, recommendations for future work are provided.

Chapter 2

Sustainability and Waste Management

Chapter Aim:

The aim of this chapter is to introduce the concept of sustainability and then to properly contextualise it in the field of waste management. It will thus pave the way for an introduction of management tools that can be used to address sustainability within waste management.



Chapter Research Objectives:

⇒ ***Contextualise*** sustainability and its application to organisations.
⇒ ***Provide*** a holistic understanding of waste management with respect to sustainability.
⇒ ***Identify*** tools to support sustainable waste management.

2.1 Sustainability and Sustainable Development

Sustainable Development (SD) has become a key term used by environmentalists and governments. Despite this the concepts of 'sustainability' and 'sustainable development' are often prone to misuse. This section will attempt to explain the various ideas and definitions regarding SD and sustainability. The two terms are regarded as being working versions of each other.

The second section of the literature explores waste management and the efforts that have been made to reconcile it with sustainable practices. "Setting out to 'achieve' sustainability is a bit like seeking the elusive state of economic 'equilibrium', the nirvana of neoclassical economists: It rarely, if ever, exists - and when it does, only fleetingly" (Shriberg, 2002). The idea that becoming sustainable is a fixed target is an illusion, as theories and concepts of sustainability are constantly being updated, advanced and challenged.

2.1.1 Background

Since the sustainability movement first came into being, many different commissions, organisations and scientists have tried to define and clarify the meaning of sustainability, sustainable development and sustainable economics. Some have described it as an ethic (Leopold, 1949), an ideal end-state, and a moral principle (Viederman, 1995). Two sustainability movements will provide background to the modern concept of sustainability.

The original term was coined by Germanic countries, in the 18th century. The countries were highly dependant on the forest and forestry as an industry. The pioneer of the first movement, Carl von Carlowitz, was the superintendent of the Saxonian silver mines. The mines were heavily reliant on timber and it was soon recognised that German forests were in a very bad state. "Nachhaltigkeit", the German term for sustainability was coined for the good practice of cultivating the forests. von Carlowitz, is thus the founder of the *Law of Sylvaculture*. The law states that no more wood should be taken from the forest than can grow back in the future. Von Carlowitz also recognised the relationship between the environmental, social and economic factors. He published his work, "Sylvacultura Oeconomic" in 1713 and it has became one of the most influential books in the field of sustainability (Kloepffer, 2008).

The second movement originated in the area of renewable resources and has thus become a broad slogan that has been adopted by the environmental movement. Lele (1991), describes the literal, ecological and social side of sustainability. Each extract offers a different interpretation and arrives at conclusions that differ and complement the various areas in which it is used.

Many businesses, whether they are private or public, in South Africa have begun to incorporate the concept of sustainability to their operations. The focus of their businesses range from mining and heavy industry, to services and manufacturing. The questions companies have begun asking themselves are: What kind of corporate citizen do we want to be? How do we treat the surrounding community? Can the environment sustain the pollutants that we are introducing? How do we handle pollutants? Essentially, companies and businesses are asking: Are we working towards sustainable development or against it?

Definition

Blackburn (2007) describes the principle of "2 R's" (Respect and Resources) of sustainability and how definitions fit into this criteria. His descriptions will be used to highlight some of the more noteworthy definitions that are currently in use.

Daly (1997) notes that sustainability is a development that has -"no throughput growth beyond the regenerative and absorption capacities of the environment." The more generally accepted definition was, however, established by the Brundtland Commission, formerly the World Commission on The Environment and Development (WCED). Brundtland and Khalid (1987) described sustainable development as:

> "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Sustainability-Integrated Guidelines for Management (SIGMA) has given another meaning than was suggested by the Forum for the Future (FORUM). SIGMA is a joint venture between the United Kingdom Department of Trade and Industry and FORUM. FORUM describe five types of sustainable capital that need to be managed and enhanced:

1. Natural Capital (the environment)
2. Human Capital (people)
3. Social Capital (social relationships)

4. Manufactured Capital (fixed assets)

5. Financial Capital (sales, shares, profit and loss, etc.)

Sustainability is achieved by living from and not degrading these assets (Sigma, 2003).

Lastly, Blackburn (2007) uses the World Wildlife Fund, World Conservation Union and United Nations Environmental Programme (UNEP) to define sustainability: "Improving the quality of life while living within the Earth's carrying capacity."

Many authors have criticised the definition as being to broad and unspecific. Richards and Gladwin (1999) describes the idea as being "fuzzy, elusive and contestable for some time to come." This flaw can create problems within an academic or political sense, as the concept and goals of sustainability can be moulded and interpreted as it is needed. This is, however, not always a problem, as Kidd (1992) points out, "the roots of the term 'sustainability' are so deeply embedded in fundamentally different concepts, each of which has valid claims to validity, that a search for a single definition seems futile. The existence of multiple meanings is tolerable if each analyst describes clearly what he means by sustainability."

These definitions are only a small number of the many definitions that are available. They are, however, the most relevant in creating an idea of what is required when evaluating all aspects of a running business. The concept of 'needs' and the idea of limitations, are imposed by the state of technology and social organisation on the environment's ability to meet present and future needs (Brundtland and Khalid, 1987).

The working definition that will be used for the rest of this thesis, is thus derived from Brundtland and Khalid (1987) and stated by Dyllick and Hockerts (2002). Organisational sustainability can accordingly be defined as meeting " the needs of an organisation's direct and indirect stakeholders (such as shareholders, employees, clients, pressure groups and communities), without compromising its ability to meet the needs of future stakeholders as well" .

2.1.2 Concepts of Sustainability

Sustainability is often associated with the broader notion of sustainable development and the terms are used interchangeably with one another. This causes problems, because it undermines the other forms of sustainability, as they are often pushed into the background. Lele (1991) notes that "most people use the phrase 'sustainable development' interchangeably with 'ecological sustainable development' or 'environmentally sound development' ".

From the working definition three fundamental elements of sustainability can be identified. Elkington (1998) describes the dimensions as 'three pillars', or similarly 'the triple bottom line' (Gladwin *et al.*, 1995), of sustainability of the: environment, economy and society (see Figure 2.1). Elkington believes that the three pillars are inter-related and influence each other in multiple ways . A brief explanation of each pillar will be provided using the definition of sustainable capital as support.

Environmental Sustainability

Environmental sustainability is the most extensively defined and researched area within sustainability. It is based on the premise that on a finite Earth the depreciation of natural capital cannot go on endlessly.

Brundtland and Khalid (1987) notes explains that natural capital can take two forms. On the one hand, natural resources are consumed during economic activity. They can either be renewable (for example fish, crops, wind power) or non-renewable (for example fossil fuel, biodiversity).

On the other hand, ecosystem services (such as waster purification, climate stabilisation) are a form of natural capital. Lovins *et al.* (1999) estimates that the value of ecological capital is at least $ 33 trillion. This however does not take into account

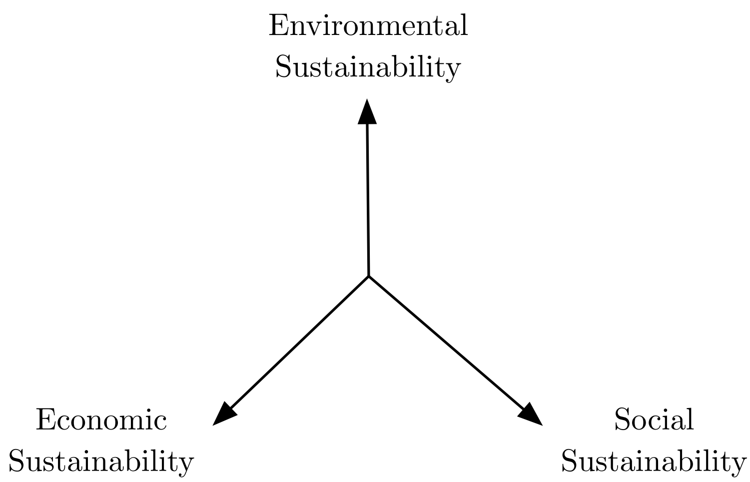


Figure 2.1: Dimensions of sustainability (Dyllick and Hockerts, 2002)

that some services can not be replaced by man.

Other ideas such as, carrying capacity, limits to growth and the maintenance of ecosystem services, have also become topics synonymous with the general notion of environmental sustainability (Mihelcic *et al.*, 2010). A definition, derived from Dyllick and Hockerts (2002), for environmental sustainability can read as follows:

> *Ecologically sustainable organisations consume natural resources at a rate 'that does not exceed' the reproductive rate and they do not allow emissions that accumulate in the environment at a rate beyond the capacity of the natural system to absorb and assimilate these emissions.*

Economic Sustainability

The economic system that provides humans with material goods is sourced from nature. We are therefore still dependant on natural systems for food and resources to sustain us. Gladwin *et al.* (1995) states that a prosperous economy depends on a healthy ecology, and vice versa. Manufactured and financial are the two respective forms of economic capital, as Dyllick and Hockerts (2002) notes that a company cannot exist without any economic capital.

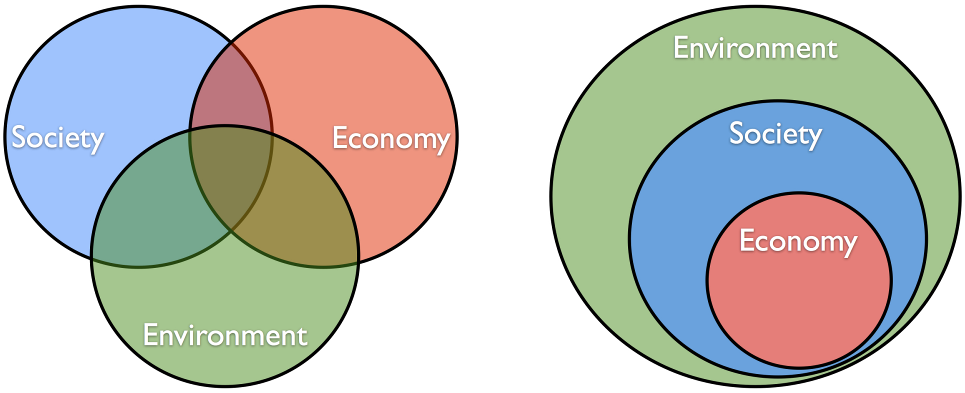
Without funding or investment, in a capitalist world, there will be no chance to develop a sustainable society. Shriberg (2002) states that although economic sustainability has widely been accepted by environmentalists, it has also been generally ignored by economists, policy makers and Decision Maker (DM)s. A summarised explanation for economic sustainable can be stated as follows:

> *Economic sustainability requires that companies have sufficient cash flow to present an above average return to shareholders.*

Social Sustainability

This is a subject which has traditionally been hard to define and analyse, in terms of the broader context in which it is placed (in terms of the triple bottom line). Social equity and biospheric respect are required for enhanced welfare anywhere on the planet. In order to improve biospheric, improved human welfare and social equity are necessary, this in turn facilitates social sustainability (Gladwin *et al.*, 1995).

Human and social capital address the issues within social sustainability. Human capital is concerned with the skills and loyalty of employees. Social capital, on the



(a) Weak Sustainability (b) Strong Sustainability

Figure 2.2: Strong vs. Weak Sustainability (Hediger, 1999)

other hand, incorporates quality of life and cultural aspects which are part of every society. Dyllick and Hockerts (2002) notes the difficulty in meeting the expectations of different stakeholders at the same time, as trade-offs must continually be made. The following definition is thus derived from Dyllick and Hockerts (2002):

> *Social sustainability adds value to communities by increasing the human capital and furthering the societal capital of these communities. Social capital must be managed in such a way that stakeholders can understand its motivations and can accept an organisations value to the system.*

As demonstrated in the previous text, sustainability is far more than a biophysical problem. It is a human development problem that contains ethical, cultural and social, religious, political and civil issues. In short, humans must change the way in which we view things. The myth that we operate considering only economic wealth is a thing of the past as we begin to realise our dependance on the environment we live in (Stead *et al.*, 2004).

The traditional paradigm of the triple bottom line of sustainability, as described by Elkington (1998), is considered weak sustainability. This will be this section's starting point and the newer concept of strong sustainability will be described. The two concepts outlined are considered to be on the opposite ends of sustainable literature. The difference can be visually defined as seen in Figure 2.2. The two views both attempt to describe the boundaries, within which an enterprise can operate while keeping the three pillars in mind.

Weak sustainability

Weak sustainability is the traditional and current sustainability principle which describes each pillar as a part of a whole, and each is considered equal (phase2.org, 2010), as in Figure 2.2a. This can be compatible with environmental degradation if suitably compensated by growth in Hicksian income[1]. In other words, economic capital is able to take the place of natural capital or natural capital the place of social.

Cabeza Gutés (1996) describes weak sustainability from an economic perspective. Sustainability is thus equivalent to non-decreasing *total* capital stock. The concept therefor does not restrict the substitution between different pillars or forms of capital. Hediger (1999) concludes that this does not conform to the definition of sustainable development that requires the integrity of the entire ecosystem be sustained throughout all activities.

Strong sustainability

Strong sustainability, however, inherently assumes that there are some forms of natural capital that can not be substituted by man made capital (Cabeza Gutés, 1996). It is rooted in the theory of ecological economics and thermodynamics. It requires that certain physical properties of the environment be sustained (Hediger, 1999). The principle is based on the fact that all human life and activity takes place within the closed system of the Earth. These include all functions which occur, within society and the economy.

Strong sustainability is represented in Figure 2.2b. It can be seen that, in contrast to weak sustainability, it considers the environment as central to all social and economic activities. In other words social and economic activities only take place within the environment. Going one step further, economic activities can only take place within society.

This implies an "ecological value principle" which measures to total "value" of natural capital from an ecosystem perspective. In contrast, to make it an operational principle, the above criterion of constant natural capital has been translated into principles of "safe, minimum sustainability standards" (Costanza *et al.*, 2009). These imply a set of ecological criteria which every project should meet (Costanza *et al.*, 2009; Daly, 1997).

[1] John Hicks defined earnings as the amount of income that can be consumed during a period while leaving the firm equally well off at the beginning and end of a period Bromwich *et al.* (2010).

2.1.3 Sustainability and Managing an Organisation

This section will look at management and reporting of sustainability that have been established. It will build on the three dimensions of sustainability and link them to the sustainable management of an organisation. Despite the existence of two contrasting views in theory, weak sustainability has seemed to be dominant in establishing of criteria and organisational management.

Beyond the Business Case

The section will be based on the work that was done by Dyllick and Hockerts (2002). It explores the link between the three dimensions, or the three pillars of sustainability. Traditional management theories have attempted to present the 'business case' for sustainable development within an organisation.

This is however an incomplete as shown in the previous section. A natural and societal case for sustainability must also be made. A firm that operates past the carrying capacity of the environment can never become truly sustainable and the same can be said for societal sustainability. Six criteria have been selected by Dyllick and Hockerts (2002) in order to enforce the sustainable case for the business, natural and societal case for sustainability. The three cases and six criteria are summerized in Figure 2.3.

The business case for sustainability relies on the efficient use of natural social resources. Through eco-efficiency a business can deliver goods or services in a manner which is beneficial to the business, stakeholder and does not exceed the Earth's carrying capacity. Socio-efficiency requires that a business maximises social impacts (such as employment) or minimise negative impacts (which may include accidents at work).

The natural case for sustainability relies on the eco-effectiveness and sufficiency of criteria, that look at ecological sustainability as their main goal with business and society as the drivers for producing greater environmental good.

The societal case for sustainability consists of ecological equity and socio-effectiveness. The management of ecological equity lies between managing natural capital and social sustainability. It is the line between what we consume at the moment and we allow future generations to consume. Social sustainability requires an equitable solution for the distribution of natural capital.

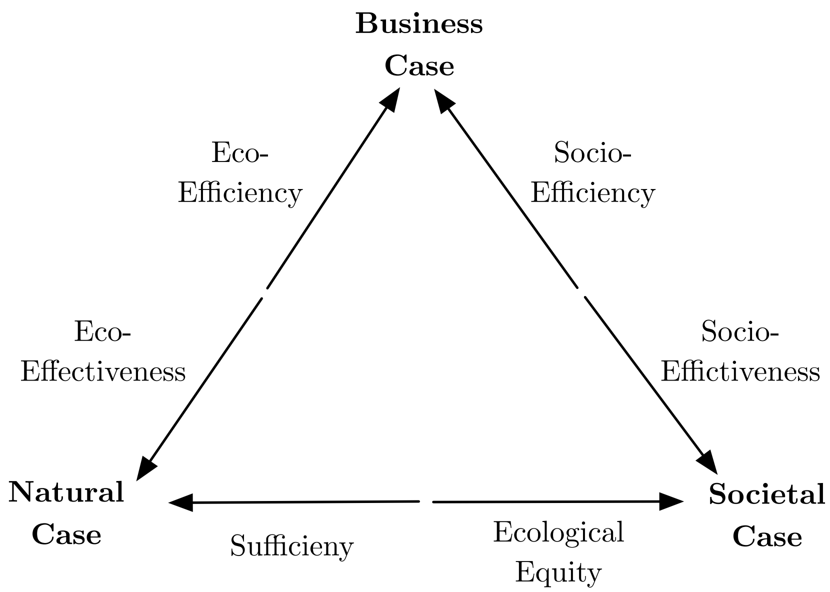


Figure 2.3: Corporate sustainability (Dyllick and Hockerts, 2002)

The literature will now look at reporting and ethical guidelines that have been established for social corporate governance.

Reporting on Sustainability

Managing sustainability is a relatively new responsibility for many companies and governments. The King Report on Corporate Governance, the latest version known as King III, is a code on corporate governance that has become the basis of operations for many companies that are listed on the Johannesburg Stock Exchange (JSE) (King, 2009). In an interview King stated that, "governance, strategy and sustainability should be inseparable from and integrated into the DNA of an organisation" (Stewart, 2010). Within King III, the idea of being a good corporate citizen means being sustainable. One of the ways in which this is promoted is through the advancement of integrated reporting of an organisation.

Over the last ten years there have been a number of standards published that have integrated sustainability with the financial and non-financial information in one report. An example of sustainable reporting is the Global Reporting Initiative (GRI). A non-profit organisation that promotes sustainable reporting within business and produces the worlds leading standard in the field of sustainability reporting, also known as triple bottom line (TBL) reporting or corporate social responsibility (CSR) reporting (GRI, 2011).

GRI (2011), defines sustainable reporting as “the practice of measuring and disclosing, and being accountable to internal and external stakeholders for the organisational performance towards the goal of sustainable development." The framework set out by the GRI, allows an organisation to report on outcomes and results of sustainable performance in terms of strategy, commitments and management. Reports can be used for the following purposes as indicated by (GRI, 2011):

- Benchmarking and assessing, with respect to norms, codes, performance standards and voluntary initiatives;
- Demonstrating how the organisation plans to influence and is influencing expectations for sustainable development; and
- Comparing performance between different organisations.

From the work conducted by the King Commission the issue of sustainability has been made relevant and an ethical imperative. The policies that companies employ have consequences not only on the financial sphere of their business but on the environment and society as well (Stewart, 2010). This translates into all economic activities conducted by an organisation including waste management.

2.2 Waste Management

Literature on waste management is extensive and has a very big base of knowledge from which to draw. This section will seek to evaluate the current literature pertaining to key concepts and practices within waste management and later its sustainability. The focus of waste management in this section will be MSW.

2.2.1 Solid Waste Management

Waste management is the collection, transport, processing or disposal managing and monitoring of waste materials (Mihelcic *et al.*, 2010). The processes are crucial as they serve a basic human need of cleaning our living environment, which in turns ensures clean, healthy and aesthetically pleasing surroundings. Figure 2.4, represents a typical solid waste system. The sources represented in the figure include residential, commercial, construction and demolition works and institutions (Mihelcic *et al.*, 2010). The area shaded in green represents the traditional realm of solid waste management, as defined by UNEP (2005) .

Storage of waste varies widely across the world. Waste is stored at a point before it is collected. The type of storage unit, determines the means of transport used in collection. In South Africa, the typical urban storage methods include wheelie bins, metallic bins for ash and bins with plastic liners. Storage must allow for separation at source, in other words the separation of recyclable and non-recyclable waste materials.

Collection and transportation incorporates the use of trucks or compactor vehicles for the majority of urban areas in South Africa. The timing of collection is an important factor in determining frequency. Collections can range from predominantly once a week for households, to daily for restaurants (organic waste decomposes quickly). Once collected, the waste can either go to a transfer station to be sorted, or be disposed of at landfill. Once the waste is sorted, it is again collected and can either be incinerated, recycled, composted or taken to landfill (Mihelcic *et al.*, 2010).

The policies employed in a waste management system affect every aspect of the waste system it manages (Choe and Fraser, 1999). As a crude example, let us suppose that waste system policy is framed according to the waste hierarchy. The system therefore promotes the reduction of waste at source as its top priority. If the waste generators adhere to the policy, less waste will be stored, transported, recycled or sent to landfill. Choe and Fraser (1999) explain that waste polices and planning need

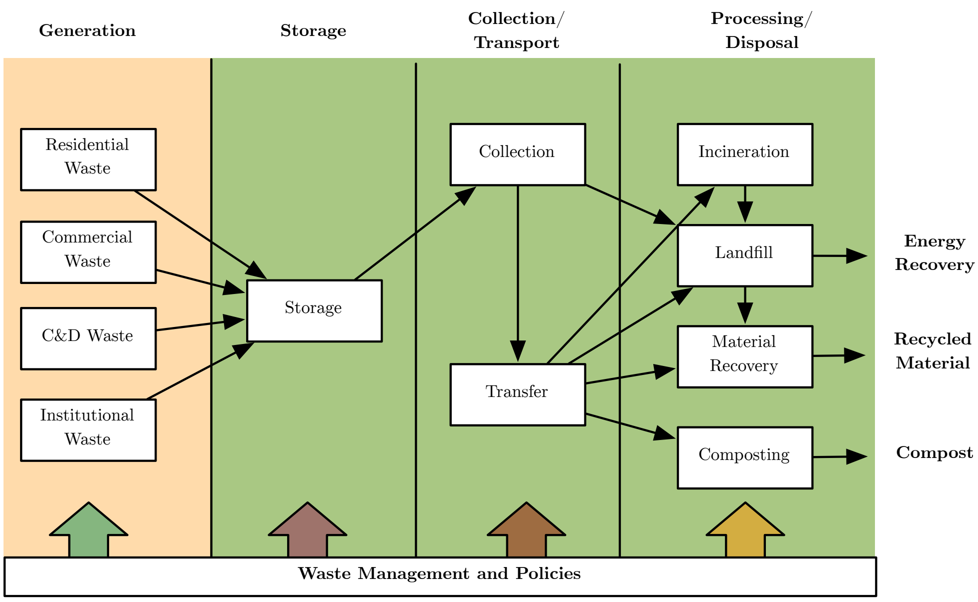


Figure 2.4: Solid Waste Management System Overview (Mihelcic *et al.*, 2010)

to be comprehensive and include every facet of a waste system.

2.2.2 Integrated Waste Management

Integrated Waste Management (IWM) is a holistic and comprehensive framework that recognises the entire life cycle of a waste system that its impacts. Nordone *et al.* (1999) define Integrated Waste Management as:

The combination of waste streams, waste collection, treatment and disposal into a practical waste management system that aims to provide environmental sustainability, economic feasibility and social acceptance for any specific region.

This can be achieved by combining a range of treatment options, including waste reduction, re-use, recycle (waste hierarchy), composting, bio-gasification, thermal treatment and landfilling (Spamer, 2009). Spamer (2009) found that the only real options of waste management available in South Africa are the reduction, recycling, composting and the disposal of waste to landfill.

IWM systems are highly dependant on the local conditions. A system that is used by one municipality, which incorporates recycling and landfilling, might be quite different to another municipality which uses recycling, composting and landfill. It must be noted that there is no one universal 'best' system that can be applied to all cases (Morrissey and Browne, 2004). Referring to Figure 2.4, the orange shaded are is now included into the system that is management (UNEP, 2005).

The level of integration within any IWM system is heavily dependant on the location which it is used in. A system which uses incineration with energy recovery and landfilling, will be very different from another which includes recycling, composting and landfilling. Again, it is crucial to remember that the single foremost objective of the IWM is to find the most environmentally friendly, economically effective and socially accepted IWM for a specific region, city or community (UNEP, 2005).

There are many different policy principles and options created which use IWM. The policies have been created in order to support the IWM . Policy options have been based on a either the waste hierarchy or Zero waste to landfill. The options and goals can either be used separately or combined, depending on the needs of the waste system.

Table 2.1: The waste hierarchy (Engledow, 2007).

The Waste Hierarchy	
Cleaner Systems	Prevention Minimisation
Recycling	Re-Use Composting Recovery
Treatment	Physical Chemical Destruction
Disposal	Landfill

Zero waste to Landfill

Zero waste to Landfill is a long-term goal attainable through a systematic and incremental approach. The approach calls for continuous improvement, innovation and creativity. Zero waste, also described as "100% efficiency", ensures avoidance of the generation of waste, minimisation of waste. Zero waste should not be interpreted as the generation of no waste. The aims of this philosophy, according to Ginindza (2012), are "too minimise waste generated as far as is technologically and economically feasible, and whatever little waste is generated should be put to some effective use". Sustainable technologies, for example the recycling of paper, environmental technologies that will help achieve zero waste (Ginindza, 2012).

The development of the zero waste end goal has been implemented in countries such as the United Kingdom and Taiwan. The most extreme case of its application can be found in Abu Dhabi, where Masdar is set to become the worlds first zero waste city. If any waste that is produced it is of guaranteed to be recycled or at least is incinerated to produce electricity.

Waste Hierarchy

Strategies for sustainable waste management seem simple enough. The waste hierarchy is shown in Table 2.1. The hierarchy has been used to classify waste minimisation strategies (Spamer, 2009). At the top, it promotes strategies and management that emphasise waste prevention and minimisation, in other words limiting waste entering the system. This translates into a cleaner system. On the level below, recycling within a system promotes the re-use, composting or recovery of materials. On the penultimate level the treatment of waste can be conducted by physical, chemical or destructive means. The lowest priority must be the landfilling of waste.

Using a management perspective, the hierarchy emphasises the need for separation at source, the re-use or at least the recycling of materials (Van de Klundert and Anschütz, 2001). By separating at source, the quality of materials that are used or recycled improve greatly. It also reduces the amount of energy used in collection and improve working conditions.

Policies that are founded on the waste hierarchy try to maximise the recovery options and minimise disposal, through controlled disposal and landfilling. As a last resort, once all possibilities for recovery have been exhausted, policies based on the hierarchy promote the safe disposal of waste materials. Thus limiting the negative impact on the environment and natural resources as much as possible (Van de Klundert and Anschütz, 2001).

The hierarchy is endorsed by the National Waste Management Strategy (NWMS), (Government of South Africa, 2000). The model focuses on a paradigm shift from 'end-of-pipe' treatment ideology of waste, to the prevention or minimisation of waste products. It also emphasises the need for an integrated waste management approach.

The waste hierarchy has been used heavily in the planning of the NWMS. It is imbedded in the facet of the Waste Act (DEAT, 2010).

2.2.3 Sustainability in Waste Management

The back end of sustainability is what can be considered as waste management. In all areas of sustainability, the basic theoretical principles must be applied. This includes the need for waste management to be done in a manner that is regarded as sustainable. "The primary target of Municipal Solid Waste Management (MSWM) is to protect the health of the population, promote environmental quality, develop sustainability, and provide support to economic productivity" Henry *et al.* (2006).

The United Nations Food Programme (UNFP) define IWM as "a framework of reference for the design and implementation of waste management techniques that can analyse and improve existing systems." McDougall (2001), goes further to define sustainable waste management, "as waste management systems that are environmentally effective, economically affordable and socially acceptable for a particular region and its individual circumstances." Therefore its integration with IWM, is the next significant element which allows for the sustainable management of waste. So sustainability within waste management must include (Van de Klundert, 1999):

- using a range of inter-related collection and treatment options, at different habitat scales (household, neighborhood, city);
- all stakeholders, governmental or non-governmental, formal or informal, profit- or non-profit oriented;
- taking into account interactions between the waste management system and other urban systems.

Nordone *et al.* (1999), argues that sustainability is not simply a combination of how waste management options are used or if they can be applied at the same time, but rather the optimal combination of a single approach. The optimal approach and most decisive objective of an IWM is to minimise the social and environmental impacts while a the same maximising any economic benefits. Integrated Sustainable Waste Management (ISWM) is a model which has been applied, in order to address the integration of IWM and sustainability.

2.2.4 Integrated Sustainable Waste Management (ISWM)

ISWM can be used as an assessment tool, a method of analysing and improving waste systems or to introduce new waste elements (Van de Klundert and Anschütz, 2001). The concept was devised in order to promote "technically appropriate, economically viable and socially acceptable solutions; that do not degrade the environment." The concept of ISWM was extracted from Van de Klundert and Anschütz (2001) and Van de Klundert (1999). ISWM therefore, has multiple principles and dimensions that need to be taken into consideration.

Principles of ISWM

As an introduction, ISWM constitutes four basic principles. The principles are based on *equity, effectiveness, efficiency* and *sustainability.* They are described by Van de Klundert and Anschütz (2001) and are reflected in the South African white paper on integrated pollution and waste management (Government of South Africa, 2000) and the National Waste Management Strategy (DEAT, 2010). The white paper and national strategy emphasise the need for the aforementioned principles, as necessary elements in an integrated and sustainable waste management system.

The principle of *equity* concerns pollution and it affects on people, the economy and the development of a community, town or city. The failure of public service is often symbolised by abandoned waste. The distribution of waste services must also be distributed evenly, to all people within the system (Van de Klundert and Anschütz, 2001).

The *effective* management of waste is important, as it translates directly to service delivery objectives being met. It means that all waste is removed at the scheduled time and recoverable materials are recovered. *Efficiency* is demonstrated when the benefits of clean streets are balanced by the cost to the system's stakeholders(Van de Klundert and Anschütz, 2001) .

Lastly, the concept of *sustainability*, refers to how resources are used by the system. The resources can be human, equipment or natural. It also refers to the interplay between different social, political and technical and environmental dimensions (Van de Klundert and Anschütz, 2001).

Dimensions of ISWM

The three dimensions of ISWM are shown in Figure 2.5. The example of the ISWM shows the range of stakeholders. Public and private stakeholders account for either businesses or citizens that are directly and or indirectly affected by the waste system. Governments are responsible for regulating and monitoring waste systems. Lastly, non-governmental organisations have the ability to lobby for the sustainable treatment of waste. The different system elements and aspects of sustainability need to be interlinked in order to make a successful system.

An ideal ISWM takes into account all relevant *stakeholders* within a waste stream, and allows for sustainable principles to be implemented throughout. The stakeholders, defined by Van de Klundert (1999), can be anyone who has a relevant interest (for example DMs, council members) or is affected (for example landowners or residences) by the management of waste. Van de Klundert (1999), describes their roles within the waste system as follows:

- residents who have to place waste outside for collection and can aid in separation at source;
- municipal managers, who have the job to design the waste service, recruit workers and set the rates for user charges;
- citizens pressure municipal authorities so that services are offered in a fair, equitable and environmentally sound manner;

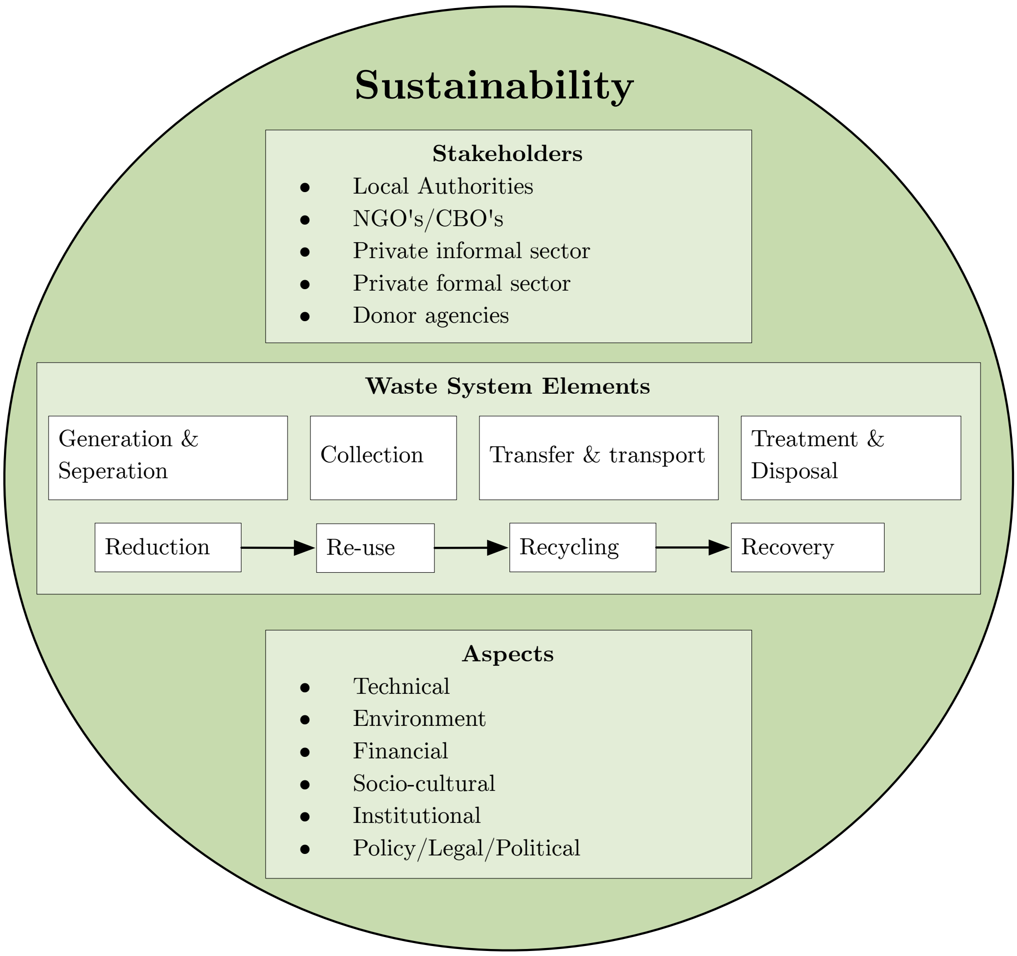


Figure 2.5: Integrated Sustainable Waste Management (Van de Klundert, 1999)

- community members can participate in neighbourhood clean-ups;
- clients pay for waste management services; and
- watchdogs are in charge of monitoring and supervising the operation of services.

The waste system, or system elements, are based on inputs and outputs. The inputs include waste, energy and raw materials. All elements within the system are in a process of movement. The outputs from the system include useful products, in the form of recycled or reclaimed materials, compost, emissions and landfill material Den Boer *et al.* (2007). Van de Klundert and Anschütz (2001) expand on the use of higher level ideas by including the waste hierarchy (a lesser known element). The reduction, re-use, recycling or recovery of waste materials should always be the top priority in a ISWM (Van de Klundert and Anschütz, 2001). These are expressed in the middle of Figure 2.5

The bottom of the Figure 2.5, adds the aspects of *sustainability* and integrated waste management. ISWM considers the full range of waste streams that can be managed. It views waste from, "an environmental, social, as well as an economic point of view" (Oelofse and Godfrey, 2008). The six aspects defined by Van de Klundert and Anschütz (2001) of ISWM include:

1. *Environmental* aspects which are focused on the effects that waste management has on the conservation of non-renewable resources; pollution control and public health. The key effects of the waste system include those on the air, water and land.
2. *Political* aspects which address the realm within which the waste management system exists. This determines the basic decision making process, setting goals and priorities.
3. *Institutional* aspects which relate to the organisational structures that control waste management. It also relates to the planning, procedure and methods used to implement sustainable waste management.
4. *Socio-cultural* aspects include the influence of culture on waste generation and management in the household and in businesses and institutions, as well as the community and its involvement in waste management.
5. *Financial-economic* aspects pertaining to budgeting and cost of the waste management system. A few issues include the cost recovery, cost reduction and the

impact of environmental services on economic activities; efficiency of municipal solid waste management systems.

6. *Technical and performance* aspects which concern the observable practical implementation and maintenance of all of the waste elements: what equipment and facilities are in use or planned; how they are designed; what they are designed to do; whether they work in practice; and how clean the city is on a consistent basis.

By integrating the six different aspects of ISWM, they are all considered in the evaluation or decision making process. The next section will briefly describe different assessment and decision making tools that have been used within waste management.

2.3 Waste Management Tools

Models and tools for waste management have been designed for many different purposes. The goal of the model could simply be to optimise the collection routes of a area or, they could be more complex, to evaluate alternative waste management strategies. For the purpose if this research, the more complex models will be considered and their advantages and shortcommings will be noted. The type of tool used, depends on the DMs' needs and the decision that needs to be made (Guitouni and Martel, 1998).

Morrissey and Browne (2004) and Finnveden *et al.* (2007) have identified many types of models that effectively tackle complex types of decision making, associated with waste management. Models that authors have identified include: risk assessments, Environmental Impact Assessment (EIA), Cost Benefit Analysis (CBA), Multi-Criteria Decision Analysis (MCDA) and Life Cycle Assessment (LCA).

Examples of persons who have completed waste management assessment, or created frameworks using these tools are extensive. A few studies which must be noted included by Kijak and Moy (2008), who combined LCA and Multi-Attribute Utility Theory (MAUT) (a branch of MCDA) to create a sustainable decision framework for waste management. Another study by Mwai *et al.* (2008) combines LCA and MCDA for an assessment and waste decision support framework for ISWM operations. Lastly, Brent *et al.* (2007) applied AHP(also a branch of MCDA) to manage decision making for developing countries within the field of medical waste management.

The models under review are all mainly analytical in nature. The three main decision aiding tools have been chosen to evaluate are: CBA, LCA, MCDA.

2.3.1 Cost Benefit Analysis

By reducing all impacts into a single measurable amount, a cost benefit analysis allows DMs to easily assess the positive and negative effects of scenarios (Finnveden *et al.*, 2007). To do this, all impacts within a given scenario are translated into monetary terms. This can be done in many different ways. For example by allocating estimated costs involved when avoiding a negative effect (like the cost of pollution avoiding a landfilling) or by determining how much stakeholders are willing to pay to improve the environment (Morrissey and Browne, 2004).

The benefits and limitations of such a decision making tool have been highlighted by Morrissey and Browne (2004):

- The results of such a study are presented in a clear manner, and summarised in a monetary figure.
- It allows DMs to see strategies use resources efficiently.
- A limitation is the uncertainty which is involved in choosing the monetary value of social and environmental impacts.
- Another limitation is the assumptions of prices can change over a given time period and change the preferred outcome.

This type of analysis is seen as an optimising model that has a single unit of measurement, usually in monetary terms (Rogers and Grist, 2001). Cost benefit analysis has been used successfully in part of developing waste management plans for the city of Dublin, Ireland. Life cycle data was converted into an economic valuation of the different environmental categories.

2.3.2 Life Cycle Analysis

A more popular tool has been the life cycle analysis or LCA. The tool can be used to investigate the potential environmental aspects and impacts, throughout a product's life (i.e. from cradle to grave) (ISO 14040, 1997). Berkhout and Howes (1997), provides sufficient case for the use of LCA's with the waste management arena. They explain that the use of LCA allows for the systematic mapping of the waste management process, which then allows for the holistic structuring and evaluating of environmental impacts of different approaches (Morrissey and Browne, 2004).

McDougall (2001), explores the link between integrated waste management and life cycle analysis. Integrated waste management combine the streams, waste collection, treatment and disposal methods. The model developed by (McDougall, 2001), is called IWM-2, which is based on IWM and LCA. There are benefits of using LCA's, but also limitations, which was again mentioned by Morrissey and Browne (2004):

- LCA's will not necessarily give the optimal 'environmental' option, but rather the option with the best performance according to the criteria used.
- LCA is but one tool that is available, and should almost never be used in isolation.
- There are some difficulties in declaring where the boundaries of an LCA.
- Different techniques of LCA's may provide different results for the same process.
- The strictly defined versions are limited to only looking at the environmental impacts.

Two models which have been used consistently within waste management are the Waste Integrated System Assessment for Recovery and Disposal (WISARD)[2] and IWM-2 models. They are based on life cycle inventory models which allow for the measurement of process "towards the goals of economic and environmental sustainability" (Morrissey and Browne, 2004). Only one item is missing and that is social sustainability, so these models can not be classified as truly sustainable waste management models.

2.3.3 Multi-Criteria Decision Analysis

Real world decision making problems are usually too complex and unstructured to be considered through the analysis of one single criterion, attribute or point of view (Visser, 2010). MCDA has become a tool which has increasingly become adopted in the field of waste management, as it allows DMs to learn about the problem, and

[2]is an LCA software tool to help inform decision making and evaluate policy options concerning the disposal of household waste

supplies alternative courses of action, from several points of view (Morrissey and Browne, 2004).

The normal approach used in this tool, constitutes the identification and evaluation of several alternatives, in this case different waste management scenarios. The scenarios are then evaluated in terms of the of criteria that are important for the model being developed. The results is a ranking of the alternatives. The criteria which are selected, depend on the objectives of the model and therefore include environmental impact and risk assessment (Morrissey and Browne, 2004).

The benefits, noted in the article by Morrissey and Browne (2004), elaborate on the fact that MCDA is a systematic approach in evaluating policy options and help structure the problem. This can be done, because the set of multi-criteria techniques used, offer a level of flexibility and inclusiveness that other economic based models do not. The techniques also allow for the view points of stakeholders to be taken into account (Hokkanen and Salminen, 1997).

There are, however, some limiting factors which have hindered the extended use of MCDA. The solutions produced by the MCDA only allow for a compromise, instead of an "best" solution. The allocation of weights is an area which has remained subjective and therefore requires a person who has experience in the field (Hermann *et al.*, 2007).

2.3.4 The Verdict

Many researchers[3], in the fields of decision making and life cycle analysis, have recommend applying the concepts of multi-criteria decision making to LCA. The argument has also been made that LCA data are an essential part of any MCDA approach to waste management, as LCA data are used as the environmental criteria, for example carbon dioxide emissions over the life cycle of the different waste management techniques.

These tools have been combined by numerous researchers in recent years and point towards the integration of analysis and decision making tools to provide a more comprehensive management tool. The use of these tools, within a sustainable solution framework have yet to be further explored.

[3]Hertwich and Hammitt (2001); Ginindza (2012); Geldermann *et al.* (2000))

2.4 Conclusion

The literature review provided information that relates to the heart of this thesis' research objectives and identified the necessary aspects to build a solution to the stated problem.

The first section of the literature review provided a background and contextual information regarding sustainability and sustainable development. The section highlighted the fact that there are a great number of view points and mechanisms used to validate the idea of sustainable practice. The field of sustainability and sustainable development have also come with a list of detractors that have undermined the notion that development can be done in a sustainable manner.

The final part of the section concluded with sustainability within an organisation. A review of the King III was provided. It states the importance of organisations to move away from the financial bottom line, to the triple bottom line of sustainability. An overview was also provided on instruments that have been created in order to measure the sustainability of an organisation. As a result, this section established and contextualised sustainability and its application to organisations. Thus completing the first objective of the thesis.

The second section of the literature review, explored the field of waste management. A basis was established that defines solid waste management and the elements which are present within a waste management system. The section thenwent on to provide an overview of IWM. The different types of waste principles were then discussed, with respect to IWM. They included, zero waste and waste hierarchy.

The focus then shifted to address sustainability in the sphere of waste management. Sustainability within waste management was addressed in terms of what should be included in forming a theoretically sustainable waste system. The concept of integrated sustainable waste management ISWM was thus introduced. The principles of equity, effectiveness, efficiency and sustainability were found to be pivotal elements. The three dimension (stakeholders, waste system elements and aspects) of ISWM have to be incorporated to ensure a truly sustainable waste system. The second research objective was therefore completed. An overview of waste management was provided. A platform has been set for sustainability within the field and its requirements.

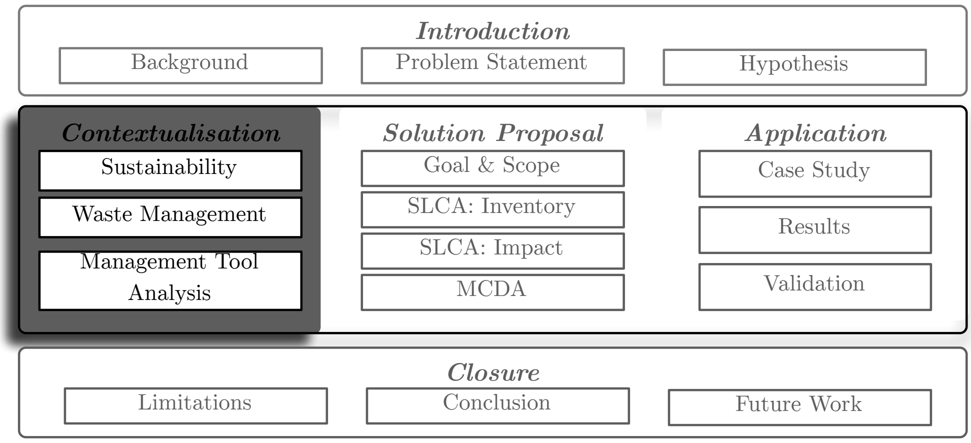
Lastly, tools within waste management were identified from literature. The tools that were tested and applied to various case studies. Three tools, LCA, CBA and MCDA, were then shortly described noting their shortcomings and strengths. From the investigation, it was concluded that LCA and MCDA warranted further study as they could be applied to both sustainability and waste management. This therefore completes the third stated objective, tools were identified which can support sustainable waste management decision making.

Chapter 3

Management Tools

Chapter Aim:

The following chapter builds on the management tools that were briefly outlined in Chapter 2. The tools are analysed in depth with the prospect of using one or both tools to construct the decision making framework.



Chapter Research Objectives:

⇒ ***Investigate*** management tools in detail.
⇒ ***Select*** tools that can be applied to a sustainabile waste management framework.

3.1 Introduction to LCA and MCDA

This chapter will focus on the two main tools, Life Cycle Assessment (LCA) and Multi-Criteria Decision Analysis (MCDA), that are currently being employed to assess waste management systems. The tools are used to understand, describe and create effective waste management strategies. They play a crucial role in aiding DMs in understanding consequences and in comparing the impact of decisions.

Godfrey (2008) evaluates the current trend in environmental and waste management assessment tools. He supports the case for a tool based on either LCA, MCDA or a combination of the two. Although other methodologies exist, the two tools have been identified as having the greatest use and detail, needed to complete a decision support framework.

As concluded in Chapter 2 the need for an integrated sustainable waste management system is crucial in reducing and controlling the creation and flow of waste through the system. The two assessment tools evaluated in the chapter are based on how well they can enhance the assessment of practices and selection of policies incorporated within an ISWM.

Their inner workings are analysed in order to see how they are traditionally used, how they work and how they can be applied in the field of waste management.

3.2 LCA and Sustainability

LCA is a tool that has been increasingly used within the field of environmental and waste management. LCA's are used to asses real and potential environmental impacts of a product's life (Morrissey and Browne, 2004). In other words a product can be followed from its *cradle*, where the raw materials are extracted, to its *grave*, its disposal.

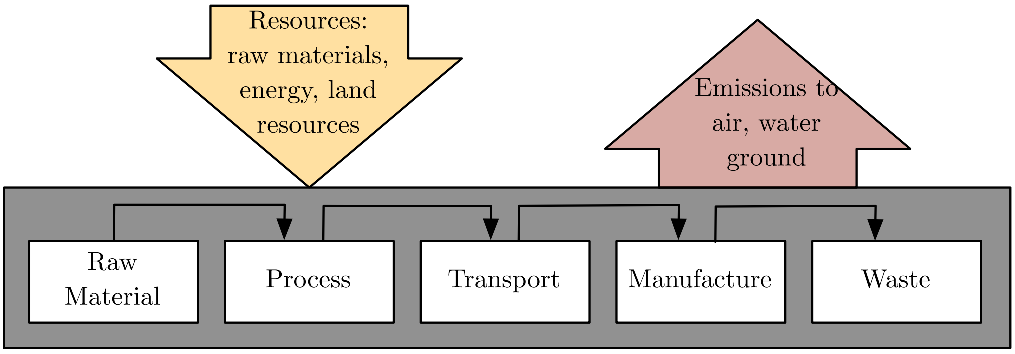
When conducting an LCA, the initial design (or development) phase is usually ignored, as it does not often contribute significantly. However, the design of a system or product has a large influence on the impacts on other stages of the product's life cycle (Rebitzer *et al.*, 2004). The design of a car is the best example, its design determines its fuel consumption, emissions per kilometer and how it can be recycled at the end of its life.

Integrated Waste Management is a combination of waste streams, collection treatment and disposal methods, with the objective of achieving environmental benefits, economic feasibility and social acceptance. McDougall (2001) developed a model in which the LCA and Integrated Life Cycle management are combined. As mentioned previously, this model was called IWM-2. Sustainable fundamentals are being incorporated within waste management in a gradual basis and the field of LCA is keeping up.

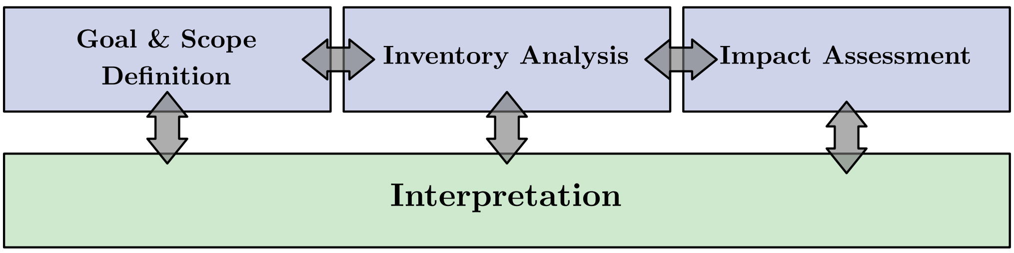
3.2.1 A Standard LCA

Guidelines for the traditional LCA have been widely published, of which the International Standards Organization (ISO) 14000 are the most well known and accepted as providing a concise framework (Rebitzer *et al.*, 2004). That is why it is described in detail and used as the basis for a SLCA.

According to (Rebitzer *et al.*, 2004) an LCA is carried out in four distinct steps (ISO 14040, 1997). From Figure 3.1, we can compare the life cycle of a product and the procedures used for conducting a sustainable LCA. A generic LCA model



(a) LCA model (Baumann and Tillman, 2009)



(b) LCA Procedure, (Mihelcic *et al.*, 2010)

Figure 3.1: A Generic life cycle model and procedure.

is represented in Figure 3.1a. The model represents the environmental inputs and impacts that is associated with a manufacturing life cycle.

The first step of the LCA procedure is the goal and scope definition, then life cycle inventory analysis, followed by a life cycle impact analysis and lastly the interpretation, which is continuous throughout the assessment (ISO 14040, 1997). These steps are depicted in Figure 3.1b.

Goals and Scope

As depicted in Figure 3.1a, the first step in an LCA is to define a goal and scope, which is considered the planning part of an LCA study (Miettinen and Hämäläinen, 1997*b*). The goal aims to state the intended audience and the application of the LCA.

The goal can be clarified by asking a specific question, which details exactly what the study has to achieve. By suggesting, "we want an LCA on our product," no specific goal or objective has been set. Instead, asking a specific question such as, "what are the main environmental problems with this product's life cycle" or "which three options will be preferred to modify this application," implies a specific environment within which the study will take place (Baumann and Tillman, 2009).

The scope on the other hand states the function or functional unit. The functional unit serves as the basis of the LCA, and is the unit used to relate all inventory and impact indicators (UNEP/SETAC, 2011). It is used as a reference for the normalisation of input and output data (Mihelcic *et al.*, 2010). In other industries, examples of functional units could be the following Baumann and Tillman (2009):

- Rope manufacture [m x year]
- Bus transport [person x km]
- Soft drink product [liters/day]

Other tasks that have to be completed in the goal and scope phase include the need to define the system boundaries. The boundaries include the physical and administrative units to be analysed (ISO 14040, 1998). Boundaries are an important methodological choice and involves the inclusion or exclusion of processes linked to a study (von Blottnitz, 2012).

In comparative studies, processes or sub-processes may well be excluded if they are the same within both comparative life cycles (von Blottnitz, 2012). The type of impacts to be considered will therefore only be different because of a different processes being considered. A standard list of impacts generally considered, such as: resources used, global warming, acidification and eutrophication. Lastly, the level of detail to be considered depends on solely on the discretion of researchers, who define the outcomes of the study (Mihelcic *et al.*, 2010).

Life Cycle Inventory Analysis

Once the goal and scope are defined, an initial flow diagram and inventory analysis has to be developed for the evaluation of processes. The inventory analysis involves describing all the inputs, within the defined boundaries, of the products's life cycle. It therefore quantifies all resources, associated with every stage of the life cycle (Mihelcic *et al.*, 2010). The first step of the inventory analysis includes describing a detailed flow chart, secondly the necessary data are collected, and lastly, the different loads on the system that needs to be calculated.

Construction of the flow model is conducted within the system boundaries as set out in the scope of the assessment. The flow chart is constructed showing the activities and the flows within the system (Baumann and Tillman, 2009). The flow chart is used to assess where potential impacts are and how they affect the impact categories that were defined.

Figure 3.2 shows the flow of materials through a system, consuming resources and creating waste outflow. The 'R' represents the resources that are required by

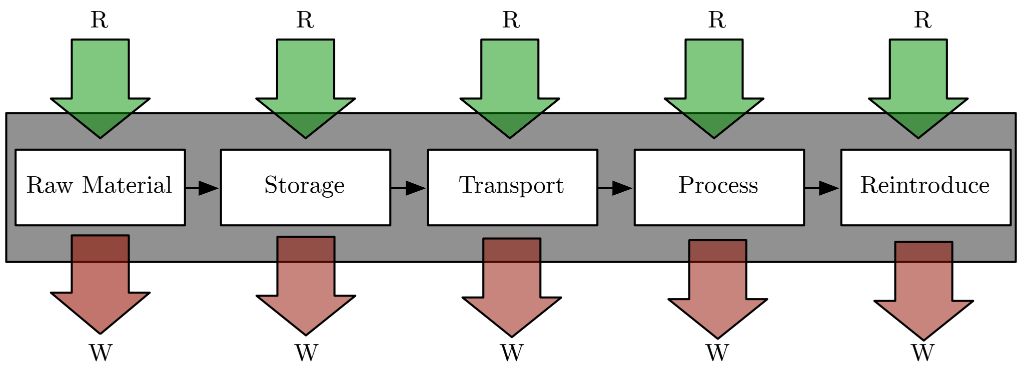


Figure 3.2: Inputs and outputs of waste system (Clift *et al.*, 2000)

the process. 'W' represents the waste that is generated by a process within waste management.

Data collection is usually one of the more time consuming activities of an LCA. It includes data from inputs and outputs of from all significant activities within a system. For a typical LCA data might include: raw materials, products, solid waste, and emissions into air and water (Baumann and Tillman, 2009). However, for a complete SLCA, data on societal and financial impacts would also be required.

"For several approaches the time and cost for a detailed LCA are judged not to correspond to the possible benefit of the results" (Rebitzer *et al.*, 2004). Thus, a simplified LCA will, in certain cases, be just as effective as an intricate and detailed assessment. Systems analysed, usually contain the same generic processes, namely: energy use, transport and waste treatment.

The calculation for a generic procedure therefore involves five steps.

1. Normalise
2. Calculate flow linking activities
3. Flows passing over system boundaries
4. Sum up
5. Document calculations

Finally, calculation is the amount of resources used and pollutant emissions with relation to the functional unit (Baumann and Tillman, 2009).

Life Cycle Impact Assessment

The third step is to conduct a Life Cycle Impact Assessment (LCIA), which is governed by the ISO 14042 standard (ISO 14042, 2000). The most important elements are considered to be (Pennington *et al.*, 2004): the selection of critical impact categories, indicators for each impact category and the model used in the LCA. Baumann and Tillman (2009) describe the impact assessment as consisting of two elements; classification and characterisation.

Classification of the chosen impact categories is the process where resources or emissions are assigned to specific impact categories. For example, in Figure 3.3, SO_2

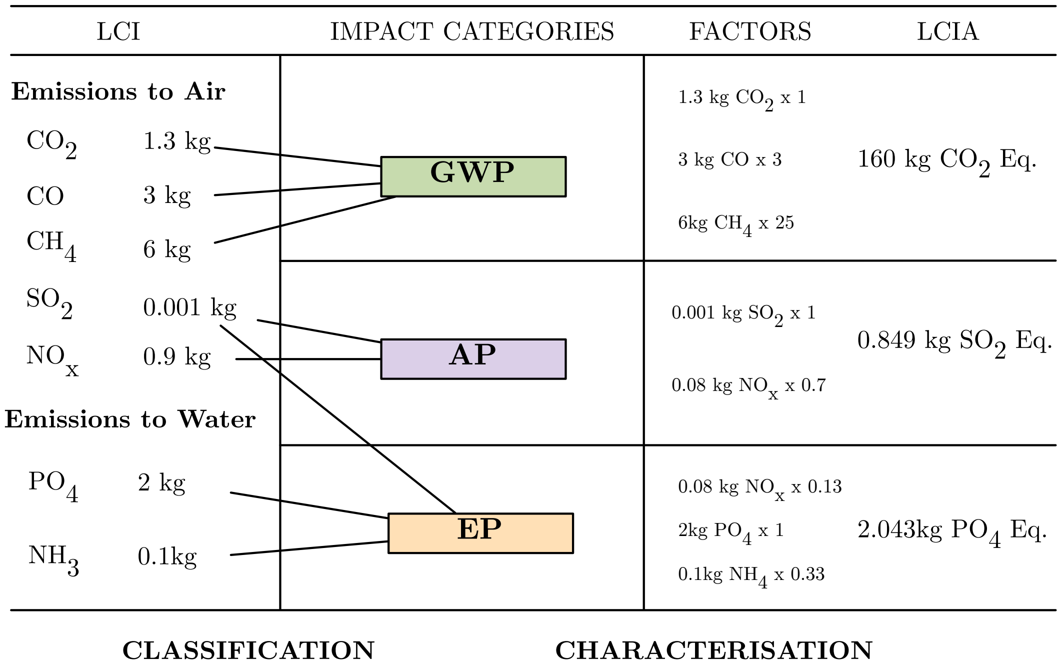


Figure 3.3: The stepwise aggregate of information in an LCA (Baumann and Tillman, 2009)

can be used to indicate Eutrophication Potential (EP) [1]. SO_2 can also be classified as having Acidification Potential (AP)[2]. Therefor SO_2 is assigned to both EP and AP. Where as a gas like CO_2 only has Global Warming Potential (GWP)[3] and is classified accordingly.

Calculating impacts from characterisation factors results in the LCIA result. For example, CO_2, CO and CH_4 have a conversion factors of 1, 3 and 25 respectively. Which means that CO has three times the GWP of CO_2 and CH_4 has 25 times the GWP of CO_2 . The factors are used to convert the different substances into one unit, and added together. From Figure 3.3 the inventory emissions result in a GWP of 160 kg $CO_2equivalent$ or $CO_2equiv.$.

[1] EP is deined as the potential to cause over-fertilisation of water and soil, which can result in the increased growth in biomass.

[2] AP is based on the contributions of SO_2, NOx, HCl, NH_3, and HF to the potential acid deposition.

[3] GWP is calculated as a sum of emissions of the greenhouse gases (CO_2, N_2O, CH_4 and $VOCs$) multiplied by their respective GWP factors

Interpretation

The last step in the impact assessment involves weighting all of the broad environmental impacts, to yield a single score for the overall environmental performance of the product, process or system being evaluated (Mihelcic *et al.*, 2010).

The outcome of the interpretation phase is a set of conclusions and recommendations for the study. According to (ISO 14040, 1998), the interpretation should include: identification of significant issues based on the results of the LCI and LCIA phases of an LCA; evaluation of the study considering completeness, sensitivity and consistency checks; and conclusions, limitations and recommendations.

Current applications of LCA, in waste management, can be found in the form of WISARD and IWM-2. These are life cycle models which allow for an overall view of a waste management system. They can be used to either compare future Integrated Waste Management options, or to optimise existing options. The only draw backs, as described by McDougall (2001), are that social and financial impacts have yet to be integrated, and they can therefore not be true sustainable waste management models.

3.2.2 A Sustainable LCA

The different components of a sustainable LCA have already been developed. The use of life cycle assessments: the environment (traditional application of LCA), costing (life cycle costing), and societal assessment.

The aim of this type of study has three benefits, as noted by UNEP/SETAC (2011). The first is that it helps in creating awareness amongst current and future DMs on the entire life cycle of a product. The second is that it assists them from a holistic perspective, based on the sustainability of a product or system. Lastly, it supports enterprises and people who are trying to reduce the degradation of the environment, prevent negative social impacts, therefore increasing the economic benefits during the life cycle of a specific product.

The growing concern, in terms of sustainability and sustainable development have become increasing popular “buzz” words and yet the uncertainty, about how one assesses and decides upon the different areas that sustainability incorporates, remains. Through incorporating a life cycle perspective to the sustainability in business, decision paradigms and frameworks can be adjusted to better meet sustainable outcomes UNEP/SETAC (2011). A sustainable LCA assesses the cycle of a product or a system from cradle to grave, or throughout the value chain.

Many organisations have been involved in trying to provide a basis for a traditional LCA. The most widely used and acknowledged is the ISO 14000 criteria and framework. The framework is, however, limited to managing the environmental life cycle of the system or product under consideration (ISO 14040, 1997). ISO have only recently begun to show progress on the issue of social corporate responsibility with the publication of the ISO 26000 set of standards (ISO 26000, 2010). Other organisations that have been promoting the ideas of three pillar sustainability are the Society of Environmental Toxicology and Chemistry (SETAC) in conjunction with United Nations Environmental Programme (UNEP). SETAC based most of their initial work on ISO 14040, but have moved and adopted a broader approach towards sustainable development. The aim is to convert the traditional environmental LCA approach into one that incorporates the development of the sustainability in an organisation.

3.2.3 The Elements of a SLCA

As discussed in Chapter 2 sustainability is focused on three fundamental areas: social, environmental and economic sustainability. Den Boer *et al.* (2007), were the first to describe an inclusive and sustainable LCA, and their work will be used as a basis for this section. It allows for the use of an assessment tool to calculate the overall picture on current sustainable performance of a service.

To create a sustainable LCA, all the impacts at every relevant stage of a product or system must be accounted for. Kloepffer (2008), championed this notion. It is therefore logical to deduce the following for a SLCA :

$$SLCA = \text{LCC} + \text{LCA} + (\text{S} - \text{LCA})$$

- LCA, life cycle assessment that deals with the environment.
- Life Cycle Costing (LCC), examines the total cost across the life a product or process.
- Social Life Cycle Assessment (S-LCA), a is a study of the social impacts of a product or process on a society.

The work has been followed by publications from UNEP/SETAC (2011), UNEP/SETAC

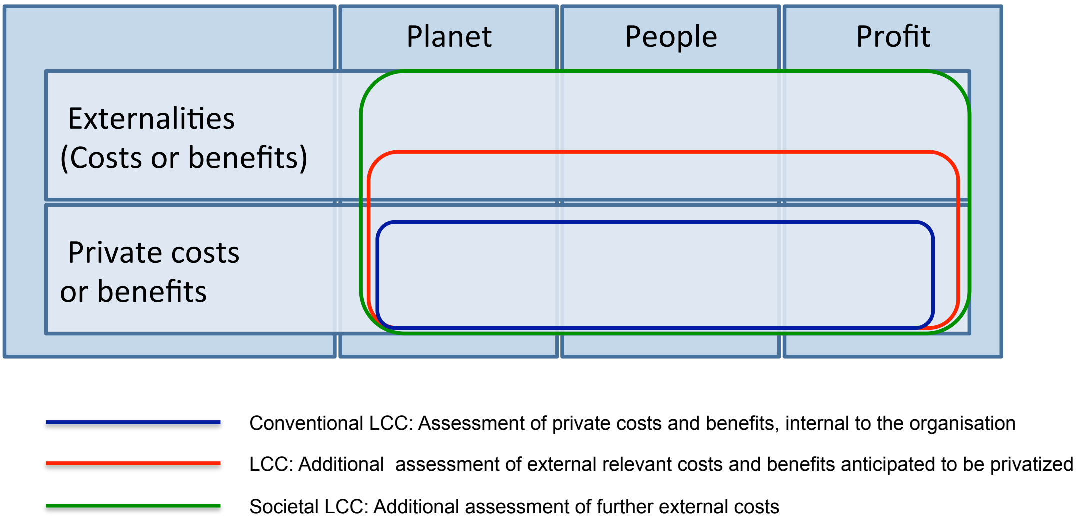


Figure 3.4: The scope of application of the three different types of life cycle costing. (UNEP/SETAC, 2011)

(2009) and McDougall (2001). Who have all expressed for the need life cycle approach when addressing the question of sustainability assessment and decision making.

Life Cycle Costing

Environmental life cycle costing summarises the costs associated with the life cycle of a product that are directly covered by one of the stakeholders within the specific LCA Kloepffer (2008).

There are three methods in which LCC can be used, as was highlighted by (UNEP/SETAC, 2011). They are represented in Figure 3.4, and can best be explained through the following:

1. Conventional LCC, that includes private costs and benefits.
2. Life cycle costing also takes into account costs which are relevant but external with benefits that are expected to be privatised.
3. Lastly, the societal LCC in which all external and internal costs and benefits are monetized.

The idea behind economic LCA is to ensure the least expensive system that is economically feasible and covers all expenses once operations have halted (Den Boer *et al.*, 2007). The sustainability of a business therefore has to operate under the premise of the following assumptions about the life cycle of a company:

- the economic sustainability of a company is related to a specific technical-organisational system and a specific DM; and
- the system operates in an economically viable manner (able to cover all expenses) for the foreseeable future.

The separation of costs and income, in waste management services, are the key points of the financial sustainability of a waste management service/strategy. An example, could be made of the costs, such as fuel, incurred when delivering services and the income, such as recycling income, generated through the recovery of raw materials and tipping fees (for municipal dumps). This is due to the fact that driving factors of costs in a waste management system are much different from the revenue that is generated.

The following criteria for indicators are considered as viable examples when assessing economic sustainability (Den Boer *et al.*, 2007):

- cost per ton/per household/per person (for entire waste system and sub-system);
- revenue recovered from recovered material;
- diversion between revenue and expenditures; and
- WMS cost as a % of operational budget.

The initial capital investment of the WMS may not be included as an indicator of efficiency, for the entire system. It is, however, very relevant when planning a new facility or system. Then all costs are converted into equivalent annual costs, taking into consideration the time value of money (Den Boer *et al.*, 2007). In theory, this idea is supported by Kloepffer (2008), who states that traditional management accounting should learn from 'environmental' LCC, and vice versa.

An LCC should therefore be used as a complementary component to an LCA, since product or services should not be unrealistically expensive and should be accepted by the market. Since the majority of consumers select a product or service solely based on price the LCC is usually used as a standalone assessment (Kloepffer, 2008). The most commonly used from of LCC is Present Value (PV). Using the PV, a set of future cash flows can be calculated to their respective present values.

Figure 3.5 visually represents life cycle stages, cost categories and production (work) breakdown. The different cost categories within the life cycle of a process.

As an example the figure extracts all labour costs associated with the life cycle stages of a process. The small block which has been extracted, represents the cost incurred during the design and development stage of a process.

A deviation in the way LCC takes place from the LCA described in the beginning of the chapter. The inventory stage is used to aggregate costs and discount future cash flows to relevant present value (including the effects of inflation), so that the most efficient strategy can be analysed and implemented. The impact phase is substituted by the cost aggregation stage that is used to add each cost to its unique cost centre.

Environmental LCA

The general objectives for environmental sustainability can be summarised as resource consumption and reduction of environmental pollution.

The selections made by Den Boer *et al.* (2007), were made in consideration of the fundamentals of LCIA and the European Union's waste management policy, these selections were confirmed by Kloepffer (2008). The LCIA research uses baseline impact categories and are recommended to be used for all LCAs. Guinée (2002) deems the following impact categories were relevant for the assessment of waste management scenarios :

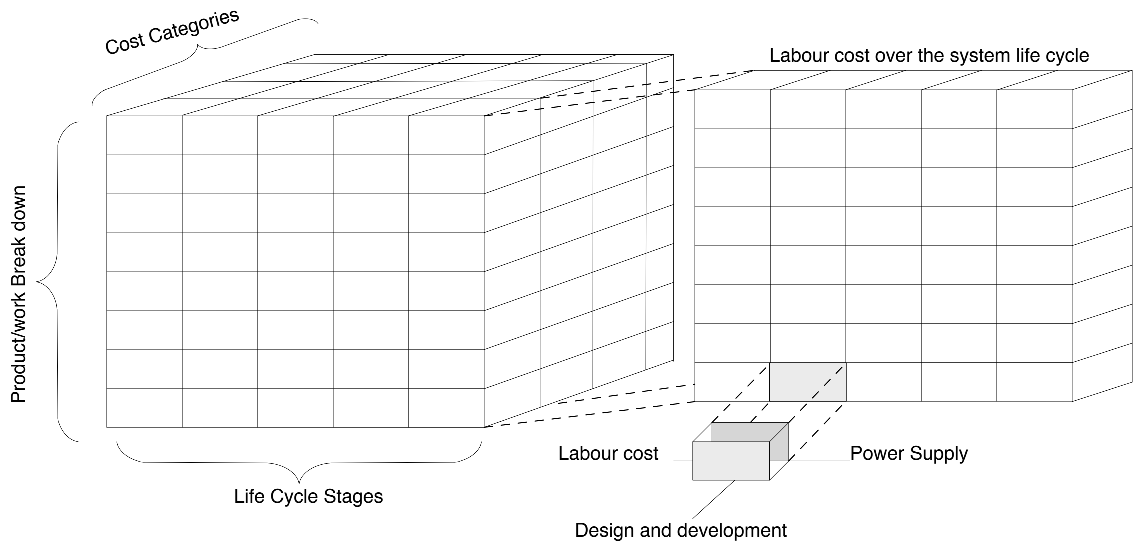


Figure 3.5: Cost categories and the share of labour in life cycle costing (UNEP/SETAC, 2011)

- abiotic resource depletion;
- climate change;
- photo-oxidant formation;
- acidification; and
- eutrophication.

The general targets of waste management set out by the European Union (EU), have been included within these criteria. There are, however, two more criteria that are (Kloepffer, 2008) :

- recovery and recycling of packaging; and
- diversion of organic waste from landfilling.

The assessment starts as soon as the waste is put into the system, (bags, bins and containers). The waste is then collected and transported to the disposal/treatment site. The disposal of waste usually refers to the direct dumping on municipal landfills. Treatment on the other hand often refers to recycling of separate recyclables, composting of biowastes or then disposal. These secondary flows are also considered in the assessment (Den Boer *et al.*, 2007).

The principle of LCA state that the firstly inputs (raw materials and energy) and then outputs(emissions to air, water and waste) must be calculated in a process called an LCIA. The results are then aggregated for the entire life cycle and can be characterised with the above mentioned indicators (Den Boer *et al.*, 2007).

Societal LCA

The social side of a life cycle assessment, is still a methodology in its infancy (Kloepffer, 2008). However, the generally accepted practice involves the measure ethical behaviour of the system being analysed. This implies that the system must be managed in a manner that is responsible to all stakeholders of the community and not just as a manner of legislation (Den Boer *et al.*, 2007).

The criteria therefore have to form part of an inclusive assessment tool. Mwai *et al.* (2008) used the following criteria to analyse the social impacts:

- social acceptability - Waste Management System (WMS) must be acceptable;

- social equity - there must be an equal distribution of WMS benefits and detriments;
- social function - social benefit of WMS.

These are now used and applied to an LCA for every process that is being analysed within a waste system. Den Boer *et al.* (2007) describes how criteria are applied in the analysis of a sustainable LCA. The processes guides the inventory side of the LCA. A comprehensive description of all criteria was described by Den Boer *et al.* (2007).

Firstly, prevention and temporary storage as a social criteria is described. Next, the convenience of temporary storage, is an indicator that describes the distance that a person has to travel in order to dispose of waste. In practice, this is a major source of convenience in Municipal Solid Waste Management (MSWM). This can be expressed in walking distance (m).

Space consumed by storage, relates to the amount of space that is typically occupied by bins, as a percentage of actual space available in the city. Another factor is complexity of storage, which describes how a person understands and uses the waste system. Finally, the distribution and location of storage, is concerned with the equal distribution and access to waste disposal facilities.

Once each of the three elements of a SLCA have been taken into account, a choice must be made. Are there going to be three individual assessments or one that includes all three elements.

3.2.4 One Assessment or Three?

From the above section 3.2.3 one can conceive of multiple ways of constructing a SLCA. Two main suggestions have been put forward on how to combine an LCA with LCC and S-LCA. These options have been presented by, Kloepffer (2008):

Option one:

The first option is based on conducting three life cycle assessments, which have consistent and identical system boundaries. There needs to be three standardised methods for conducting each assessment (LCC and LCA already have set methodologies). A formal weighting between the three areas are not considered for weighting. This, is advantageous because it allows for transparency for comparative assessments and it does not compromise between the three pillars.

Option two:

The second option allows for a single LCA to be conducted with three impact assessments. One advantage is that this would allow for only one life cycle inventory analysis to be defined in the goal and scope of the assessment.

Option one seems to be the more practical option to implement and operationalise. Kloepffer (2008), however tends to favour option two, as he states that,“ ISO 14040 and 14044 could be revised in the future again in order to comply with option two”. This would allow for the inclusion of LCC and S-LCA into the current ISO standards. In any case a more detailed guidance would be required on how to execute a LCC and S-LCA.

3.3 Multi-Criteria Decision Analysis (MCDA)

The field of Multi-Criteria analysis has, in recent years, become a popular choice to solve problems concerned with sustainable development and waste management (Roussat *et al.*, 2009). The reason why decision analysis has become a popular research field, is that it allows for the proper structuring of complex problems and the consideration of multiple criteria.

Marttunen (2010) explains that the analysis aims to highlight these conflicts and derive a way to come to a compromise in a transparent process. The MCDA is meant to be a tool to aid in the process of making decisions and how not to make them.

Where as other methods and techniques usually focus on optimising one single dimension of a problem, for example: cost or efficiency, MCDA takes different individual and often conflicting criteria into account in a multidimensional manner. The type of criteria chosen in these models depend on the objectives of the model, in the case of this thesis, sustainability.

3.3.1 Why Multi-Criteria Analysis is used

The main role of Multi-Criteria Analysis (MCA) is to handle large amounts of data. Human DMs have shown to have trouble with and handle the large amounts of complex information in a consistent way (Dodgson *et al.*, 2009).

There is usually not one unique solution to a problem and it is necessary to use DM(s') preferences to differentiate between solutions Morrissey and Browne (2004). The decision can therefore be conceived as a compromise of two components; a set of objective alternatives and subjective criteria (Buchanan *et al.*, 1999). The subjectivity of the analysis allows the user to insert their own personal preferences and guide. It also allows the tailoring of the decision making process to their own needs.

Assessment methods that are based on cost or on any other single measure, often ignore any other relevant information. MCA applications are used to assess the different parameters, some of which can not be expressed in monetary terms, or for which monetary values do not exist (Dodgson *et al.*, 2009). MCA uses judgement of individuals to contribute towards making effective decisions.

The applications of MCDA in waste management have been well documented. The two most common models that are in use are Electre III and Analytic Hierarchy Process (AHP). Other models include PRO-METHEE, ORESTE, and SMART (Simple Multi Attribute Rating Technique), but they have rarely been used in modelling waste management (Triantaphyllou, 2000).

The main assumption embodied in decision theory is that DMs inherently wish to make consistent decisions. This implies that DMs would not make DMs would not deliberately make decisions that would contradict one another. This consistency in decision making is then translated into the notions of coherence and consistency of preference leading to the transitivity: if A is preferred over B and B over C, then A should be preferred over C (Dodgson *et al.*, 2009).

3.3.2 The Fundamental Processes of MCDA

> "The goal of structuring the decision on objective and subjective components places a clear boundary around the preferences of the DM(s)"(Buchanan *et al.*, 1999).

How an MCDA works

At present, not all MCA techniques provide much assistance in terms of practical decision making, there are, however, others that offer considerable value. Figure 3.6 represents the different alternatives available and how they eventually correspond with the criteria defined by the DMs. The various techniques differ in how the data is put together (Dodgson *et al.*, 2009).

Dodgson *et al.* (2009) describes the criteria used for selecting the correct MCDA techniques as: transparent, easy to use, data requirements that are consistent with the needs of what is being studied, realistic resource requirements, probability to provide an audit trail.

The first standard feature of a MCA is the **performance matrix**. The matrix is created so that every row describes an option and every column a performance measure against every criterion. Individual performance measures may be expressed quantitively and qualitatively.

In a basic MCA, the matrix will be the final product of the analysis. It is then left up to the DMs to assess, if their own objectives measure up to the values within the matrix. The intuitive processing of the data can be used to make effective and speedy decisions. It also opens the door for unjustified assumptions that can cause the incorrect ranking of options (Dodgson *et al.*, 2009).

The weighting and scoring of options are the next steps, that are applied to more advanced analysis. Firstly, scoring is done by assigning the expected consequences of each option with assigned a numerical value. The score is based on the strength

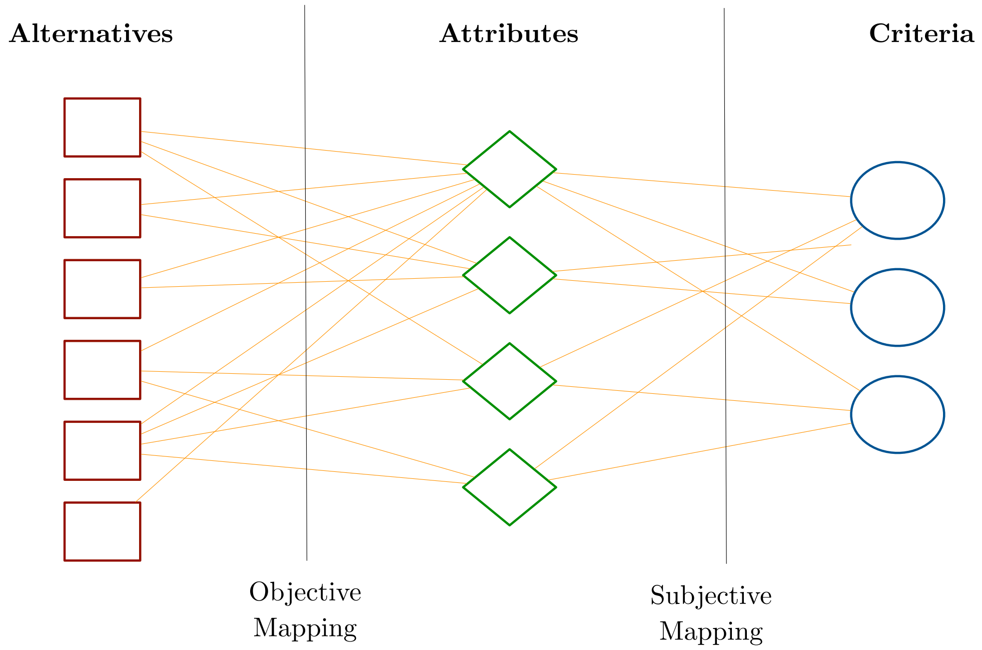


Figure 3.6: Alternative Attribute Criteria Mapping (Nahman and Godfrey, 2010)

of options and each criterion. Logically, the higher the preference the higher the assigned score and the less preferred options scores less. The scaling is usually done from 0 to 100. The second step, is the weighting applied to individual criteria. It is done to assign the relative valuations of a shift between the top and bottom of the chosen scale (Dodgson *et al.*, 2009).

The approaches mentioned in the previous chapter are referred to as compensatory techniques, since high score in one criteria might be compensated by low scores in other areas. MCDAs are progressive and iterative, that add to the systematic development of favourable decisions.

The Stages of MCDA

Dodgson *et al.* (2009), Triantaphyllou (2000) and Belton and Stewart (2002) all suggest different methodologies to complete an MCDA. The generic steps or stages described by each author, do seem to be similar. Table 3.1, represents an example of the of steps required in a full MCDA.

Dodgson *et al.* (2009) describes an eight stage methodology. The methodology describes the initial stages of establishing a context for the analysis. It then moves on to the identification of the options, objectives and criteria. The 'scoring' of options is determined by a DM.

The scoring of options allows for consistency and consequences of the decisions to be considered and formulated in a structured manner. Weighting of criteria determines there relative importance of each. By combining the respecting scores and weights, an overall ranking can be established. The ranking of the options can then be done and a sensitivity analysis completed.

The stages or steps involved ensure that consistent decisions are made. The decisions that are made are also critical in terms of how the type of information is used or discarded. This leads to a field of uncertainty within decision making.

3.3.3 Dealing with Uncertainties

As first noted in Brinkhoff (2011), Belton and Stewart (2002), uncertainty is an important part when constructing a MCDA model. The typical uncertainties consist of firstly, a natural variation and secondly, a lack of knowledge.

Table 3.1: Applying the Steps of an MCDA (Dodgson *et al.*, 2009)

1. **Establish the decision context.**
   (a) Establish the aims of the MCDA, and identify the key stakeholders.
   (b) Design the socio-technical system for conducting an MCDA.
   (c) Consider the context of the assessment.
2. **Identify the options being appraised.**
3. **Identify Objectives and Criteria.**
   (a) Identify criteria for assessing the consequences of each option.
   (b) Organize the criteria by clustering them under-high level and lower-level objectives, in a hierarchy.
4. **'Scoring' - Assess the expected performance of each option against the criteria.**
   (a) Describe the consequences of the options.
   (b) Score the options on the criteria.
   (c) Check the consistency of scores in each criterion.
5. **'Weighting'.**
6. **Combine the weights and scores for each option to derive the overall value.**
   (a) Calculate overall weighted scores at each level in the hierarchy.
   (b) Calculate the overall weighted scores.
7. **Examine the results.**
8. **Sensitivity analysis.**

Uncertainties in MCDA

According to Belton and Stewart (2002), MCDA can be further divided into internal and external uncertainties. The internal uncertainties deal with the construction of a the problem and its analysis. External uncertainties, on the other hand deals with the lack of knowledge of information that is available when creating different scenarios or choices.

There are a number of internal uncertainties that have to be dealt with and others that cannot be resolved. The latter can include issues such as ambiguity or false impressions, about the specific meaning of a criterion. Examples of these uncertainties can be unclear definitions of alternative courses of action that lead to uncertainty over which alternative to chose. The solution to this is too restructure the model, and improve the parameters of the analysis and therefore iterate the process until the correct the parts that do not work (Belton and Stewart, 2002).

Other internal uncertainties may relate to the analysis of the results obtained from the MCDA. These can stem from the specified criteria or acceptable trade-offs between performances of criteria (Brinkhoff, 2011).

Sensitivity Analysis

Triantaphyllou (2000), notes the importance of dealing with uncertainties within an MCDA model. Sensitivity analysis is a useful tool when performing that task. Triantaphyllou (2000), suggests that the sensitivity analysis for a MCDA consider aspects of:

- Impact scores (using levels of uncertainty);
- Weights within categories (i.e. between sub-categories);
- Weights between categories (i.e. relative importance of human health and safety, environment etc.); and
- Costs

Triantaphyllou (2000) suggests a different methodology for checking the sensitivity of the above criteria and options with an MCDA, for example changes to scores, changes to weights and applications of weights between, during and after remediation. This allows the user to note the relative importance of certain criteria.

According to Brinkhoff (2011), “the difference between uncertainty analysis and sensitivity analysis is that the former investigates the importance of variables for a function and the latter the uncertainties in them.”

3.3.4 What MCDA tools are out there?

A key deciding area that is used to choose between the different types of MCA techniques, is the number, alternatives that have to be evaluated. Some projects are concerned with outcomes that have an infinite degree of variability. This thesis will, however, look at techniques that are valid for a finite number of options. The main difference between the different options is the manner in which the performance matrix is evaluated. Guitouni and Martel (1998) stress the fact that there is no one super MCDA that can be used for every problem.

The options that have been repeatedly noted in literature[4] include: AHP; outranking methods; and MCA methods based on fuzzy sets.

Single Synthesising Criterion Approach (AHP)

The analytic hierarchy process (AHP), was devised by Thomas Saaty and is one of the most common multi-criteria decision techniques around. It is used to convert assessments which are relatively subjective, and give them overall scores and weights. It was devised as a linear additive model which uses pair wise comparisons and options. Guitouni and Martel (1998) explain the methodology as using "pairwise comparisons along with a semantic and ratio scale to assess the DM preference (relative measurement scale)."

The strengths and weaknesses of AHP have been well documented over the years. The greatest strength is that the process of straightforward and convenient to use. The feature is exploited by the 'MACBETH' and 'REMBRANDT' software applications to scoring and weighting.

One weakness has consistently been noted by various authors, namely Triantaphyllou (2000); Hokkanen and Salminen (1997); Salminen *et al.* (1998). A *rank reversal* phenomenon, sometimes occurs when simply adding another option to a list of options that are being evaluated. The ranking order of two options, unrelated to the new option, might simply reverse. This is inconsistent with the "rational" evaluation of options and therefore questions the theoretical first principles of AHP (Dodgson *et al.*, 2009).

Outranking Methods

These methods have their origins in France and have enjoyed practical applications in Europe and enjoy many different variations. These include the original ELECTRE and PROMETHEE methods and were followed by ORESTE, REGOME and MELCHIOR which are all based on the same theoretical framework as ELECTRE (Guitouni

[4] Brent *et al.* (2007); Guitouni and Martel (1998); Dodgson *et al.* (2009)

and Martel, 1998). The methods seek to eliminate alternatives based on the outranking, that are said to be "dominated". Weights are used as to give more influence to some criteria than others (Dodgson *et al.*, 2009).

The superior option is chosen when it outranks the others, based on the importance of the criteria and if it is not substantially inferior in any particular criterion. All options are assessed in terms of the full terms of all the other options that were considered against a set of threshold parameters (Dodgson *et al.*, 2009).

One advantage of outranking methods is that competing options can be classified as 'incompatible' (or just complex to compare). The incompatibility of options does not mean that they are indifferent towards each other, as the case would be if there was missing information at the time of the assessment. This built in function of outranking methods, allows formal analysis to be conducted without imposing a judgement of indifference or dropping the options because of lack of evidence (Dodgson *et al.*, 2009).

One concern with the outranking method, is that it is limited by the definitions of what exactly constitutes outranking and how threshold parameters are set and then later changed by the DMs. It is also limited by certain selection criteria, mentioned in section 3.3.2, such as ease of use, data requirements and software availability Dodgson *et al.* (2009).

MCA using fuzzy sets

Dodgson *et al.* (2009) describes decision making as inherently complex and has somewhat imprecise data which needs to be used. A method around that is the use of fuzzy data sets that can be used as the basis for decision making models.

Fuzzy options attempt to eliminate the lack of precision in our description of issues. The idea of something being 'reasonably unattractive' from one point of view or 'might be too expensive', not just simply 'unattractive' or 'expensive'. These nuances are captured using the idea of a membership function, through which an option would belong to the set of, say, 'unattractive' options with a given degree of membership, which would range between 0 and 1.

Fuzzy MCA's build on the degree of membership and set out a procedure for aggregating fuzzy performance levels using weights. The fuzzy methods have however been criticised for a lack of theoretical foundation and the difficulty of non-specialists to not only understand and execute.

3.3.5 Choosing the Appropriate MCDA Technique

There are a great number of varieties of MCDA that are currently in use. That is why Guitouni and Martel (1998) tentatively outlines seven guidelines that can be used in choosing the most suitable format. These guidelines are represented below:

1. Determine the stakeholders of the decision process. If there are many DMs (judges), one should think about group decision making methods or group decision support systems (GDSS).

2. Consider the DM 'cognition' (DM way of thinking) when choosing a particular preference clarification mode. If he is more comfortable with pairwise comparisons, why using trade off's and vice versa?

3. Determine the decision problematic pursued by the DM. If the DM wants to get an alternatives ranking, then a ranking method is appropriate, and so on.

4. Choose the multi-criterion aggregation procedure (MCAP) that can properly handle the input information available and for which the DM can easily provide the required information; the quality and the quantities of the information are major factors in the choice of the method.

5. The compensation degree of the MCAP method is an important aspect to consider and to explain to the DM. If he refuses any compensation, then many MCAP will not be considered.

6. The fundamental hypothesis of the method i to be met (verified), otherwise one should choose another method.

7. The decision support system which accompanies the method is an important aspect to be considered when the time comes to choose a MCDA method.

These guidelines enable the DM to evaluate the correct type of analysis which will suite the situation. The results of the work done by Guitouni and Martel (1998) will be used to aid in the selection of the appropriate tool that will become critical if applied to a sustainable waste management.

3.4 Selecting a Tool (LCA vs. MCDA)

The above tools are both viable options to be used in the management of waste and achieving sustainable objectives. Both tools do, however, have limitations in how they acquire and use data to make decisions. The limitations are noted in Table 3.2, as constructed by Morrissey and Browne (2004) .

The limitations that are noted in the table do seem to be complementary. The limitations include the fact that an LCA cannot guarantee that a superior product or service is selected. An MCDA, on the other hand, allows for different criteria to be taken into account and supply a selection based on a systematic process.

The most notable limitation, when using an LCA, is that no guarantees can be made that the correct option will be chosen. An MCDA allows for a mixture of

Table 3.2: LCA vs. MCDA (Morrissey and Browne, 2004)

	LCA	**MCDA**
Benefits	Allows for trade offs between different products/systems to be assessed.	Allows for a systematic approach to policy and problem solving.
	Fair and holistic assessment that reviews a product, process or service from cradle too grave.	A mixture of qualitative and quantitive data can be used and compared.
	Comparative LCA can give a clear indication of better product, process or service.	Flexible and inclusive that traditional economic models do not have.
Limitations	Different results can be obtained using different methods of LCA (e.g. investigating the same product).	Personal judgment may be required and experience is required.
	Can only asses environmental tradeoffs. Although social LCA's are becoming more frequent.	Allocation of weights are subjective and affect end results.
	Cannot "guarantee" in choosing an superior product or service.	Some techniques used are very cumbersome and unwieldy.

qualitative and quantitative data to be analysed and guide DM towards the best set of options.

Two of the benefits that are noted, when using an LCA is that is allows for a holistic assessment of a process and that LCA's can be used comparatively. This is in contrast to using a MCDA, where assessments may be limited to the experience of DMs, this is due to a lack of data being available.

The benefits and limitations of each tool can, however, be integrated. An integrated approach has been put froward and demonstrated by many researchers, such as Mwai *et al.* (2008); Miettinen and Hämäläinen (1997*a*); Hermann *et al.* (2007); Benoit and Rousseaux (2003). Allowing the shortcomings of one tool, to be compensated by the benefits of another.

Decision analysis and life cycle analysis, have been and can, be combined to provide a targeted approach towards analysing the current systems, and outcomes of future systems. This is particularly applicable when analysing the impacts that waste systems will have on sustainability.

Through deductive reasoning based on the literature reviewed, an LCA would be the basis for a given framework. The MCDA would then be integrated allowing for a structured decision analysis of different waste management options. Thus, an LCA can be done and feed the necessary information so that a full decision analysis can be completed.

3.5 Conclusions

The aim of this chapter was to complete the two research objectives, as stated in Chapter 1. The first objective was to gather information and the second was to make a selection of which tool is to be used as the basis for the decision support framework. The investigation of the two tools provided crucial background information. The information provided insight into the selection, usage and implementation of LCA and MCDA.

LCA was firstly described within the realm of sustainability. The research shed light on the why a SLCA is relevant and helpful towards DMs. The study then shifted to the basic principles of conducting an assessment: defining the goal and scope; conducting an inventory analysis, measuring impact; and lastly interpreting the results. The study then move back to sustainability within LCA and the three spheres of environment, society and economy. Lastly, it established whether the three components must be used within one study or if three separate studies should be performed. The first option was considered the most appropriate when applied.

The attention then shifted to the field of MCDA. Firstly, the background was described and its usefulness within various different types of data. The fundamental issues were then addressed regarding how MCDA are applied and how uncertainties are addressed when completing an analysis. The literature then move to the different types of MCDA that have been developed and when they are useful. Lastly, a selection of guidelines were provided, in order to help when choosing between the various MCDA techniques. Therefore, the first objective was accomplished. A detailed investigation was completed around the two tools that could be used as a basis for the decision framework.

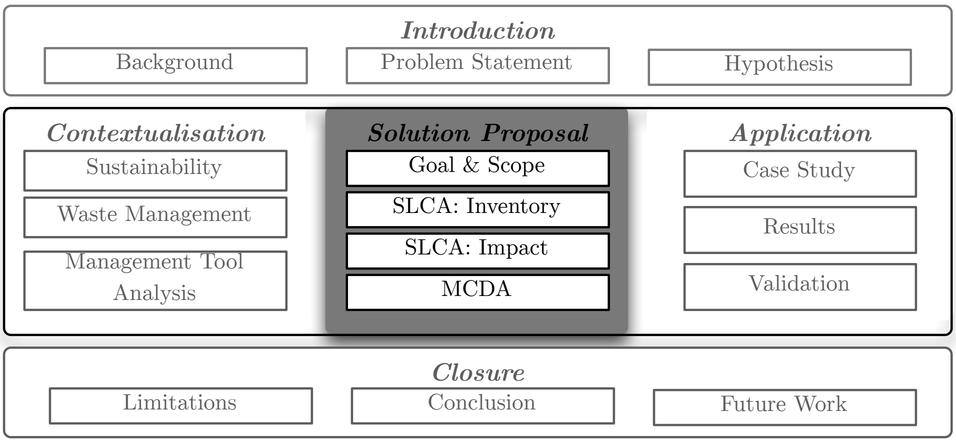
The last section deal with the selection of the tool which would be used. The conclusions from the analysis conducted was that neither tools investigated should be used individually. They should rather be integrated and compliment each other's limitations. The second objective of the chapter was thus achieved. Both tools were selected for the framework to be constructed in Chapter 4.

Chapter 4

Building a Sustainable Framework

Chapter Aim:

Chapter 4 sets out to construct an integrate framework using LCA and MCDA. The framework is constructed to facilitate decision making, based on sustainability, within waste managament. The framework is to be developed and applied to SU.



Chapter Research Objectives:

⇒ ***Construct*** a decision support framework.

4.1 Design

The problem statement in Chapter 1 proposed that sustainable analysis and decision making within Waste Management System (WMS) can be aided by LCA and MCDA. This chapter thus seeks to construct an integration of two tools, LCA and MCDA in order to analyse and provide decision support to supplement current waste management policy decisions. The literature review introduced sustainability and noteworthy shortcomings pertaining to assessment and decision making within the field.

Chapter 2 introduced sustainability in the context of IWM and highlighted current management tools that are being used. Chapter 3 went further and clarifies SLCA, an expanded form of LCA, as a tool that can be used to analyse the sustainable performance of a WMS. Chapter 3 also highlighted MCDA, particularly AHP, as a tool that could aid in consistent and accurate decision making.

Chapter 4 now aims to develop a framework that utilises the three dimensions of ISWM. The framework will firstly evaluate the state of a WMS using SLCA and then to decide on the best course of action (Policy Based) based on AHP. A four stage approach is proposed to construct the waste management framework. The developed approach is illustrated in Figure 4.1. The figure incorporates the SLCA stages of: Goal & Scope, Inventory Analysis, Impact Characterisation and is completed with an AHP.

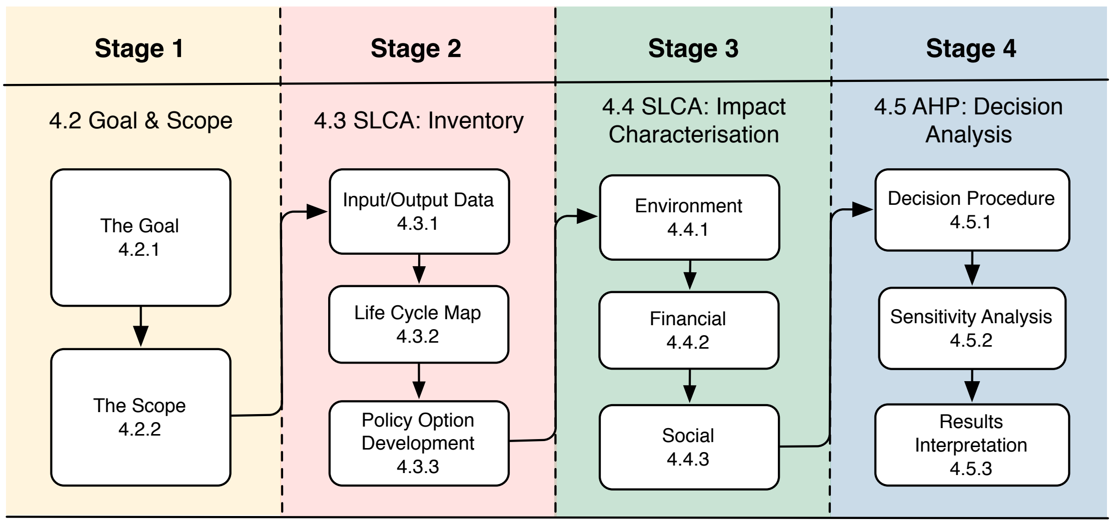


Figure 4.1: Decision framework design.

Stage 1 - Goal and Scope

This stage defines the goal of the SLCA. The intended results of the SLCA portion of the SLCA are stated. The scope of the study is then defined by a set of boundaries and impact categories. The boundaries define the space within which the framework will be applied. The impact categories are then defined by six criteria that will measure the impact on the three pillars of sustainability.

Stage 2 - SLCA: Inventory Analysis

After the goal and the scope for the study have been outlined the second stage of the framework establishes the sustainable inventory that is present within the system. The impact results are derived from the inventory data captured. A life cycle map is then used to capture the flow of waste from the cradle of the system to its grave. On the basis of the life cycle map, a baseline scenario is created. The baseline is used in order to derive multiple waste management policy options. The different policy options are assessed by the impact analysis.

Stage 3 - SLCA: Impact Analysis

Once the inventory data has been gathered, and policy options have been created, the data is classified according to impact categories. To complete Stage 3, the impacts are classified and characterised according to each criteria. The results of the impact analysis are used by decision makers in order to complete the framework.

Stage 4 - AHP: Decision Analysis

This stage draws upon the results generated and consolidated from the impact analysis. The consolidated information is used by decision makers in order to rationalise and evaluate the results of different policy options. A sensitivity analysis is conducted and the results are discussed following ISWM.

4.2 Stage 1 - Goal and Scope

This section sets out to clearly state the goal and scope of the framework. ISO 14040 (1997) states that the goal of an LCA shall, "unambiguously state the intended application, the reason for carrying out the study and the intended audience." Firstly, the goal of the framework will be stated and then the scope will be addressed. The scope will define three main elements of the framework the: research scope, impact categories and boundaries of the framework.

4.2.1 Goal

The goal of this framework is to support sustainable decision making on waste management policies. The framework will incorporate the tools of SLCA and AHP. The tools will be used to gather information on the current state of the system, and then use the information in a structured decision making process. The framework will seek to improve how decision makers interpret and use information in selecting policy options based on sustainability.

4.2.2 Scope

The scope of the SLCA and MCDA is defined by the following sections that will elucidate the rationale behind choosing the location, boundaries and impact categories that define the main structure of the framework.

Research Scope

The boundary of this framework focuses on SU and its stakeholders. The stakeholders that are considered for this study, include the following persons:

- Students that live or study on the main campus of SU.
- Faculty members of SU's main campus.
- Facility labourers, of SU or organization, who handle waste directly within the system under consideration.
- Waste or grounds managers at the SU's facilities management.

The framework first seeks to identify the largest fractions of waste materials within the system. The materials are then tracked from cradle to grave in order to document inputs and the outputs associated with the different stages of waste management.

Environmental, financial and social impacts within the different stages of a waste system storage, collection, processing, landfilling and recycling are then identified. The framework considers six impact categories that encompass the three pillars of sustainability. The impact criteria for the SLCA and AHP are selected so that they are both relevant and complete the framework. The three objectives and criteria are compiled using the reporting guidelines as stipulated by the GRI (2011) and Fedrigo and Hill (2001).

Impact Categories

The impact categories used reflect sustainable development principles. The categories represent the environmental, financial and social impacts of waste management policy options. Baumann and Tillman (2009) and von Blottnitz (2012), support the use of indicators that serve management goals and can be used to discriminate between alternative options.

The environmental categories are listed in Table 4.1. *Carbon Footprint* and *Recycle Rate* are selected because they can be easily understood by decision makers. They are used above more commonly expressed environmental criteria, such as acidification, eutrophication or water use. The time period considered for environmental impacts is one year.

Carbon Footprint accounts for the release green house gasses by a person or organisation. This measure can also be called the global warming potential or GWP100. GWP100 relates to the impact of green house gasses over a 100 year period. It is measured in metric tons of $CO_2 equiv.$ that is released into the atmosphere for a year. The measure takes into account nine common green house gasses (Methane, Carbon Dioxide, Nitrous oxide, CFC-12, HCFC-22, Tetrafouromethane, Hexafluoromethane, Sulpher hexafluoride, Nitrogen) Trifluoride (Baumann and Tillman, 2009).

The *Recycle Rate* of the system is an operational measure. It describes the true rate of recycling that is required within a given year for the system, in order to understand operational requirements for the waste system. It accounts for any inefficiencies that may occur either through process or storage. The rate only takes into account non-organic recyclable materials that are introduced into the waste system, for example plastics and glass. Organic recyclable materials such as food are not considered.

Table 4.1: The list of environmental impact criteria.

Item	Name	Definition	Unit
1.	*Carbon Footprint*	The total set of greenhouse gas emissions caused by an event, product or person recorded over one year. The time horizon for its impact is 100 years, as developed by the Intergovernmental Panel on Climate Change (Goedkoop *et al.*, 2008).	$MTCO_2$ *equiv.*
2.	*Recycled Rate*	This category is concerned with the amount of recyclable waste needs to be recycled. Den Boer *et al.* (2007) notes that the use of a goal impact, is necessary to account for waste targets, for example as those set by the EU	*% Waste Recycled*

A financial assessment is required of SU and must form a private cost perspective as per UNEP/SETAC (2011). The financial impact criteria are represented in Table 4.2. Most waste management policies are driven mainly by budgetary concerns for many institutions. The goal of the financial review is thus to complete that function and asses the financial decisions made by the University, at individual waste management life stages.

The LCC methodology that is used looks at the *Net Present Value Net Present Value (*NPV)of the waste system. This allows for all income and expenditure to be recorded. It is calculated by taking the value of inflation and risk into account. The

Table 4.2: The list of financial impact criteria.

Item	Name	Definition	Unit
3.	*Net Present Value*	The operational value of a policy option. The NPV represents all cash income and expenditures that are associated with waste management activities	*Rands*
4.	*Recycling Value*	The value of organic compost or recycled material produced by the University. All recyclable waste within the system is accounted for and an overall received value is calculated.	*Rands*

Table 4.3: The list of societal impact criteria.

Item	Name	Definition	Unit
5.	*Employment Potential*	The current or potential future employment that can be created or lost as a direct result of the WMS (Den Boer *et al.*, 2007)	*Persons*
6.	*Acceptance*	Manner in which the end point of a waste stream is considered on an acceptance level by the stakeholders of the University.	*No Units*

result represents a relationship for economic efficiency that can be used to evaluate different policy options, as used by Baumann and Tillman (2009).

The *Recycling Value* that could be withdrawn from the system is all waste that can be sold as recycled material. The results allow for a demonstration of value that can be extracted from the entire system. Value refers to the raw (or unaltered waste) recyclable materials current market value.

Social impacts deal with two social functions of waste management. The social functions occur during different processes within the waste system. Social impacts will not be time dependant but will rather focus on societal issues that are directly affected by waste management. The social impacts are recorded in Table 4.3. The impacts selected represent social equity in terms of the *Employment Potential* that is offered by a specific waste management option. Employment potential is a measure of work, which is directly created through the application of the WMS.

Social Acceptance represents the stakeholder acceptance of the options that are under the consideration of the decision makers. The assessment focuses on the function of stakeholders who are directly affected by the waste system. It includes stakeholders who are part of the system's operations or who benefit from making use of the system.

Boundaries

The system's boundaries are universal for the waste system being analysed. Redundancy is prevented by ignoring impacts that remain consistent throughout the evaluation of different policy options. The system boundaries include:

- The operations within the University which involves handling of the predefined types of waste.
- Private contractors and Stellenbosch Municipality who handle waste from the University.
- Only waste created from within the selected system is studied.

Inputs and outputs of the waste system will only be recognised if it has direct and significant bearing on the following waste management operations: storage, collection, transport, processing, recycling and landfilling.

The waste life cycle is defined by five stages and progresses from the cradle of waste, through an intermediate phase and concludes at the grave. The stages and boundaries are depicted in Figure 4.2.

The cradle is defined by storage; any item that is deemed to be waste, and is disposed of within a specific waste receptacle from SU. It is followed by the intermediate stages of transportation and processing. The grave is the point where the waste is either disposed on a landfill, or recycled (recyclers are not included). Recycling includes composting that is the only waste reclamation process to be studied. This approach was applied by Vossberg (2012) and Baumann and Tillman (2009).

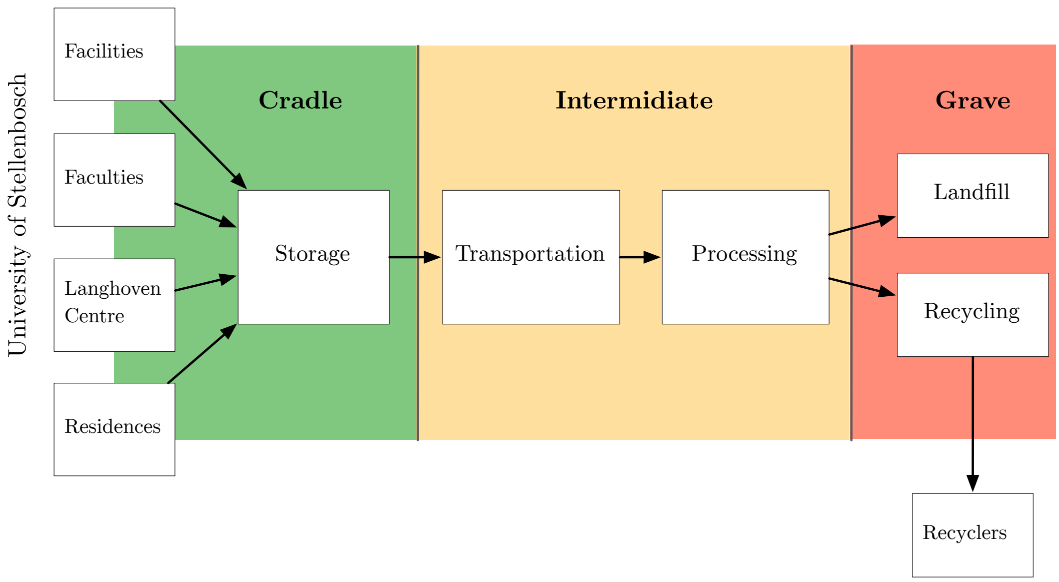


Figure 4.2: The stages and boundaries of waste life cycle.

4.3 Stage 2 - SLCA: Inventory Analysis

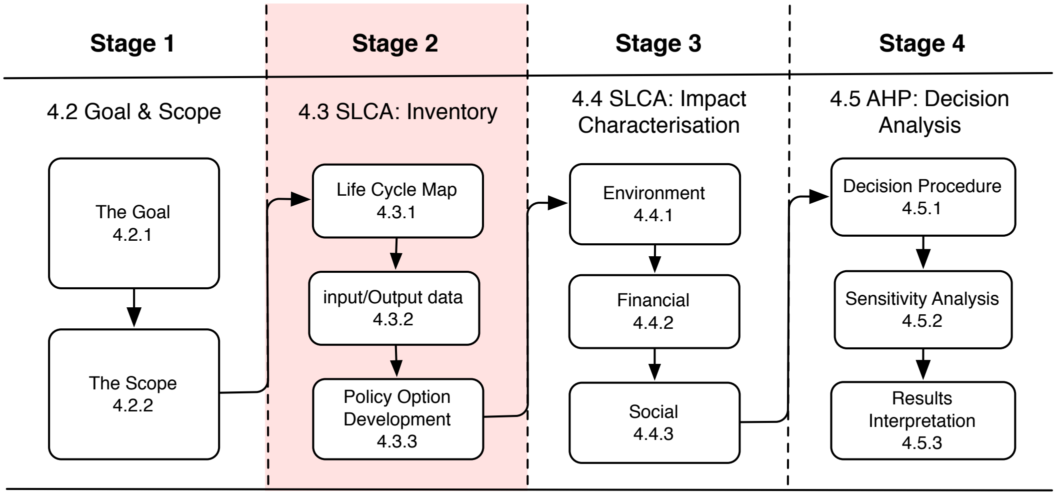


Figure 4.3: Stage 2 of decision framework.

The inventory analysis is done to map processes and gather data relevant to each stage of the waste management life cycle. Baumann and Tillman (2009) and UNEP/SETAC (2011) assert that inventory data be useful and relevant towards specific impact categories chosen in Chapter 4.2.2.

The inventory analysis consists of two sections; data capture and the life cycle map as represented in Figure 4.3. Data capture will be used to document the inputs and outputs of the WMS. The life cycle map will be split along the three sustainable categories and track the flow of waste within the system.

4.3.1 Life Cycle Map

A life cycle map is the basis for an inventory analysis. As stated previously, the map represents the specific life cycle boundaries, resource and material flows, and the process involved in handling the waste at a specific point in time. As first noted by Baumann (1998), the processes are never as simple as initially anticipated. Therefore, the map is iterative and "enlargements" of the processes are made to add detail.

The construction of the life cycle map is done through the characterisation of individual categories of waste, which is discussed in further detail in Chapter 4.3.2.

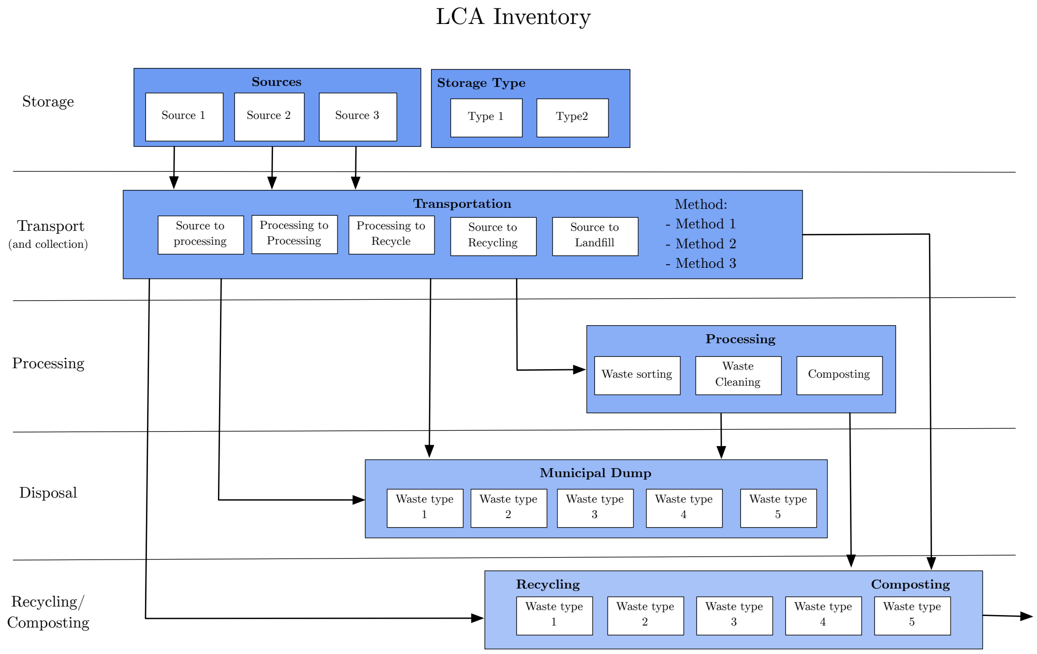


Figure 4.4: The life cycle map to be used to evaluate the waste flow within the University

The life cycle map is developed according to the five stages that are considered for the WMS. The stages include: storage, collection, transport, processing, recycling and then landfilling. Within these categories all of the sustainable inputs and outputs associated with the waste flow can be assessed.

In Figure 4.4, an example of waste flow through a WMS is illustrated. Within the five stages, different processes have been identified that are relevant to the waste system under investigation. A processes may affect one, two or all three of the sustainability impact categories. For example during transport the following sustainable inventory can be noted: financial inventory such operations and fuel cost, or environmental inventory such as Green House Gasses (GHG).

Storage

Storage defines how and where waste is stored and is the first step in the waste management process. This is the point at which waste from a household enters the waste stream. Three sources will be considered as they are assumed to cover the majority of any campus waste. The sources include any building that forms part of the SU's main campus. It mainly consists of residences, academic buildings and sporting facilities. Appendix A.1, indicates the main buildings that are serviced by

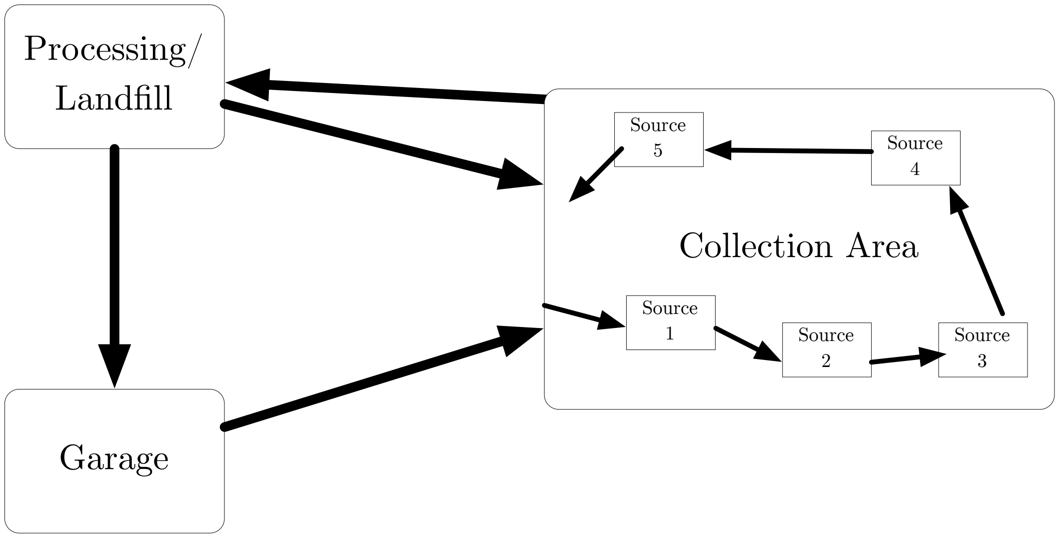


Figure 4.5: Collection and transport for the average case for a South African waste collection service

SU's WMS.

It is assumed that all of the above mentioned sources are serviced either externally by a contractor or the local municipality or internally through the SU's WMS. Den Boer *et al.* (2007) uses the typical volumes used to pick up the bins within, in this case the common 120 *litre* black wheely bin. The bin is the standard waste container for the University.

Transport

Transport is defined as the collection of recyclable and commingled[1] waste. It is transported through various sizes of trucks to four areas, namely: the garage, landfill, processing and the recyclers.

Figure 4.5, shows the most common collection and transport scheme for municipal waste removal services. The inventory model will seek to average the distance travelled between the three areas. The distance will be averaged to a year. The type of transport is noted. Different forms of road transport have different fuel and haulage efficiencies. For this study only one fuel efficiency has been identified and used. The efficiency takes into account the entire distance of a trip , that includes trips to landfill and processing. It has allowed only variables of distance, between destinations to be considered.

[1]commingled waste is considered a mixture of recyclable and non-recyclable waste.

Processing

The intermediary stage of the waste life cycle, processing, deals with the separation of waste. The separation of waste usually takes place at a transfer station. Processing is the manual separation of waste into different categories. The different categories of waste are then either recycled or taken to landfill.

Recycling and Landfilling

The grave at one of the last two stages of the waste cycle is considered either recycling or landfilling. The processing of waste will allow for specific waste flows to be tracked to their respective graves. Recycling and final disposal have very distinct differences in terms of financial, social and environmental inventory. Recycling and landfilling were selected as they are used by both the local municipality and the SU.

Recycling will be counted as having a positive effect on the environment. Recycling occurs at various facilities in and around Cape Town. Recyclers have not been considered for this study, however the inventory data related to recycling is considered within a financial, social and environmental sense.

Landfilling, on the other hand, is considered to take place in a formal manner. It is assumed that all waste that has been quantified within the disposal flow lands up on the municipal dump. The municipal dump is considered to be the Stellenbosch's municipal dump which is located 5km from the University.

4.3.2 Input and Output Data

The next step is to identify and elaborate on the key data requirements. The data follows the waste flow diagram, shown in Section 4.3.1, from cradle to grave.

Four types of data have been identified, which are required to complete the framework: life cycle process data, financial survey, waste stream survey and social inventory. The data gathered is used to create a representation of the financial, social and environmental impacts.

Life Cycle Process Data

Life cycle process data is required to give a complete picture of the current WMS. According to UNEP (2009), process data is gathered so that a clear picture of the stages involved in the waste system can be painted.

Process data, for the waste life cycle, contain the following:

- Size of system in terms of population and services rendered.
- Process descriptions of how the different forms of waste move from cradle to grave.
- Limitations that exist within the current system.

Data is to be obtained from primary sources such as interviews conducted with managers or operators within the WMS. Other secondary sources include service provider data bases and inventory databases.

Waste Stream Survey

Accurate environmental calculations require a standard set of waste data. Data needs to be collected in terms of weight and types of waste generated by the SU. The role of the survey is to identify the quantities and specific waste composition that is produced by SU. The survey focuses on all forms of waste that can be recycled and other waste that is considered "un-recyclable" (either economically unfeasible to do or not no process exists to recycle them). The survey will be used to show the major types of waste that are prevalent within the waste system. The data gathered will then be used to calculate the sustainable impact of the main types of waste through out the waste life cycle.

The necessary data needs to be extracted either by a complete waste stream survey which contains a sample of the waste or by continuous waste tracking. Waste sampling represents an average of the waste which is disposed at any given time. Seasonal fluctuations also have to be taken into account. Continuous sampling is done by waste management companies involved in recycling. The waste which is collected is sorted into 15 categories and each category of waste is weighed. The results of either method provide weight of waste and waste fractions for the selected time frame.

Life Cycle Costing (LCC)

The cost analysis includes the revenue and costs relevant to the collection, transport, charges and operating costs of processing and dumping. As is the case with the waste stream survey, the relevance or significance of the costs can only be justified once all have been accounted for. LCC will aid in the calculation of the financial impacts and contributions that the waste life cycle will have, not only on the University but also on service providers and local government. The third source of data is SU records which will provide costing data on staff wages by the University and other service providers.

The cost analysis is to be conducted on each stage of the life cycle and within its boundaries. The cost of each category will firstly be aggregated through respective costing item that exists within the specific life cycle stage. Costing items may include:

- salaries and wages;
- fuel;
- black plastic bags; and
- personal protection equipment.

Overhead costs are to be allocated proportionately to each waste stream, based on the mass of the waste that it flows through it. This is the basis on which contractors allocate costs to SU. The income will be allocated in a similar manner, for the items that go to recycling (UNEP/SETAC, 2011).

The data is to be obtained through secondary sources such as municipal reports, University budgets and bills from service providers.

Social Inventory

The focus areas of the study, as stated in scope of the framework, will be the acceptability and equity of a particular waste system. The inventory data collected follows (to a lesser degree) work done by Henry *et al.* (2006), and to a greater extent consider the work done by Mwai *et al.* (2008).

Social equity, in context, relies on a waste management option's ability to generate employment. Sources for the social inventory data are employment data from SU, service providers and semistructured interviews with relevant managers. The targeted stakeholders were designated by there involvement with students and the waste management of the University.

Data to be collected from the stakeholders include employment figures for the people who are employed because of the waste system. An example may be within the transport of waste, which is responsible for the direct employment of one driver.

The motivation for the targeted survey is to establish a clearer picture of *Acceptability*, by selecting stakeholders within the University and those involved with the waste management operations. The data points to the *Acceptability* of a given waste option based on its performance. The performance of a system is based on the waste hierarchy of reuse, reduce, recycle and dispose. The development of performance of the various policy options are described in Chapter 4.3.3.

4.3.3 Policy Option Development

Once the results have been determined from the completed life cycle inventory analysis, the results are then expanded to include different policy options. The policies are expanded from the current waste management practice to incorporate different possibilities within the current scenario. Options are defined by the completeness of the three main levels of the waste management hierarchy;

Level 1 - Reduce or Reuse.

Level 2 - Recycling or Composting.

Level 3 - Landfill (Disposal).

Each option progressively strives to be reduce a greater percentage of waste and be more recycle intensive. An example is given in Figure 4.6. It shows five options. The options differ based on performance according to the waste hierarchy. Option

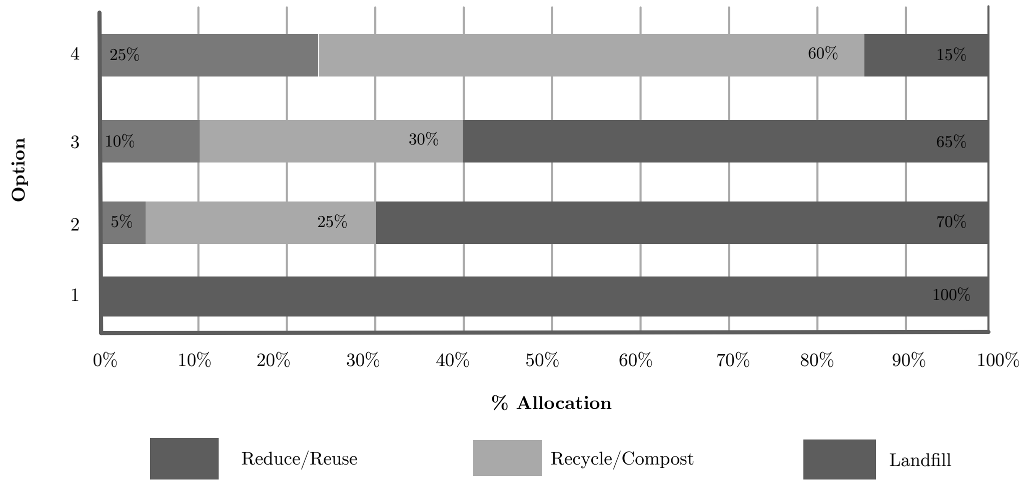


Figure 4.6: An example of how different options are created using results allocation

1, for example has all waste within the system going directly towards the landfill. Option 2, has a 5% reduction in the volume of waste from option, 25% of waste within the system is diverted to recycling and 70% of waste goes to landfill. Option 5, is the most extreme case where there is a 25% reduction in baseline waste and 60% of all waste is recycled.

4.4 Stage 3 - SLCA: Impact Characterisation

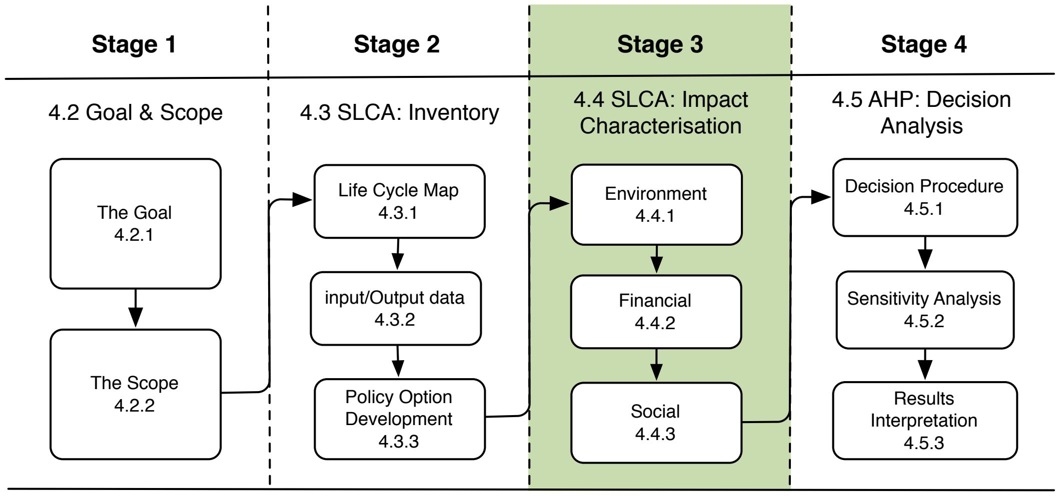


Figure 4.7: Stage 3 of decision framework.

The options developed after the inventory analysis, must be evaluated based on their respective impacts. This is done so that the consequences of the various environmental, social and economical options can be gauged. The process of evaluating the five stages of the waste system allows the decision makers to become familiar with the important processes that occur at each stage of the waste system.

The characterisation process identifies and then allocates the respective inventory data to the six impact criteria. The processes effectively incorporates the classification and characterisation steps within an LCA. The respective impacts are then translated into an easily understood dashboard in the final stage of the framework in order to aid in their respective decision making processes.

4.4.1 Environmental Impacts

The environmental impacts that have been selected, reflect the need of an organization to report and manage a waste system. From Figure 4.8, the examples of

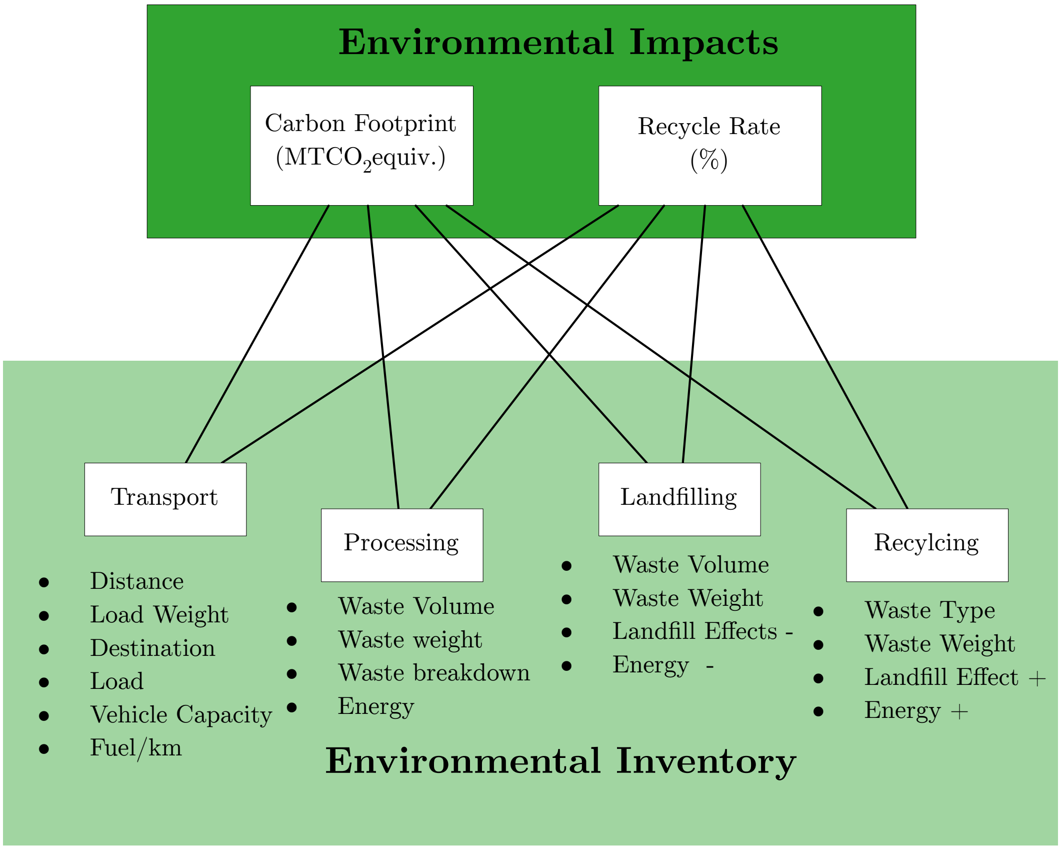


Figure 4.8: The environmental impact categories which have been selected in relation to the inventory data of the WMS life cycle

life cycle inventory data is given. The data is then related back using the *Climate Change* and *Recycle Rate* as environmental impacts.

The first indicator, *Carbon Footprint*, directly relates to the green house gas emissions that occur across the waste management life cycle. Figure 4.8, represents expected inventory data from the WMS. For example, transport distance affects the amount of fuel that is required, and the more fuel required the greater the *Carbon Footprint*.

The inventory results of all key waste groups defined in the scope of this study. *Carbon Footprint* is indicated as the global warming potential over 100 years for $MTCO_2equiv.$, (Baumann and Tillman, 2009). The WARM[2] was used to calculate

[2]WARM calculates and totals GHG emissions of baseline and alternative waste management practices: source reduction, recycling, combustion, composting, and landfilling. The model calculates emissions in metric tons of carbon dioxide equivalent $MTCO_2equiv.$ across a wide range of material types commonly found in MSW (EPA, 2012).

Carbon Footprint and was developed by the United States Environmental Protection Agency (EPA). A brief overview of the tool is provided in Appendix A.2. It aids waste managers in calculating green house gas emissions from different waste management alternatives.

WARM uses conversion factors in order to provide $MTCO_2equiv.$ of different types of waste and their respective processing methods. For example by sending a ton of cardboard to be landfilled results in 1.5 $MTCO_2equiv.$ being released. If the same amount of cardboard was sent for recycling, -5 $MTCO_2equiv.$ would be released or avoided.

The second indicator, *Recycle Rate*, was selected because it equates to the amount of recycling within a WMS. It is a measure of how much a system must be able to recycle, for a given policy option. The indicators are aggregated from the total waste that is recycled or landfilled. The impact relies on the mass of waste and the efficiency of processing and storage.

The rate is measured as a percentage of waste to landfill versus percentage to recycling. The rate can be calculated only at the end of waste life cycle, and takes only recyclable materials, not including food into account.

4.4.2 Financial Impacts

The financial impacts attempt to bring to light the costs of running a waste management system and the value that might be hidden within the waste system. Figure 4.9, represents the link between expected inventory data points and their respective impacts on the impact categories selected.

NPV accounts for the financial performance of the WMS through the different life cycle stages. The financial impacts are thus only observed from SU's perspective and does not account for any financial transactions of outside parties. The NPV takes into account all expenses and income that is generated from the waste system, for a single year. The NPV is then calculated for the different options over a five year period. The yearly escalation being 10% is used and was derived from the average increases in municipal waste tariffs. The cost escalation takes into account the rise in costs for different items such as fuel increases or landfilling tariffs. It also includes any increases that can be made by service providers. The discount rate is approximated at 12%, takes into account the current (2012/07/19) prime interest

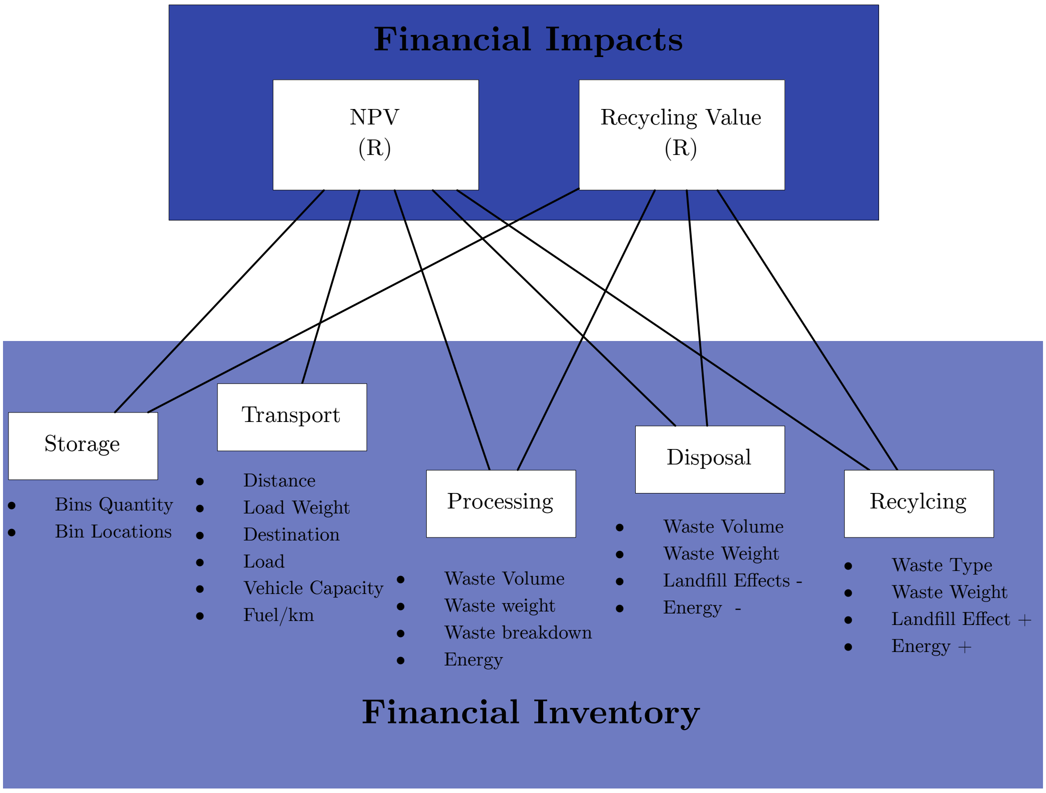


Figure 4.9: The impact categories which have been in relation to the inventory data of the WMS life cycle

rate of 8.5% and accounted for risk and inflation at 3.5% (Vossberg, 2012).

In Figure 4.9, the life cycle stages of the waste system are represented. An example can be made using the bins to be collected. The amount of bins that are collected by the municipality correlates directly to the customer pays. The municipality charges R312.45 per bins for a year. The *Recycling Value* of the waste disposed are calculated using the waste prices, the prices were supplied by roleplayer within the South African recycling industry and are shown in Appendix A.1.

4.4.3 Social Impacts

The social impacts are calculated using the two criteria that represent the equity and acceptability of a given waste management policy. Figure 4.10, represents social inventory data points that are expected to occur and that might be characterised by social impacts. The acceptability of a given waste management option can be taken into account through the use of a survey of the relevant clients of waste system. The acceptability is measured using a scoring system out of 10. If an option is a maximum of 10 then it is extremely acceptable and if it is a 1 completely unacceptable. Each option is thus to be evaluated against this scale and the results recorded. The option with the highest average score is the most acceptable. A screen shot of the acceptability questionnaire is given in Appendix A.4

The equity takes into account the employment potential of a specific policy option of the WMS. Employment potential of persons only directly employed by the system is taken into account. As can be seen from Figure 4.10, employment can be created through transportation, processing, disposal or recycling. The number of people employed by the WMS is then recorded and their job descriptions noted. The option with the highest number of potential employees is then considered the best and allocated a rating of 5. For other options the total number of employees was divided by the number of employees of the best option. The resulting percentage is then multiplied by 5, and an employment score is calculated out of a maximum of 5.

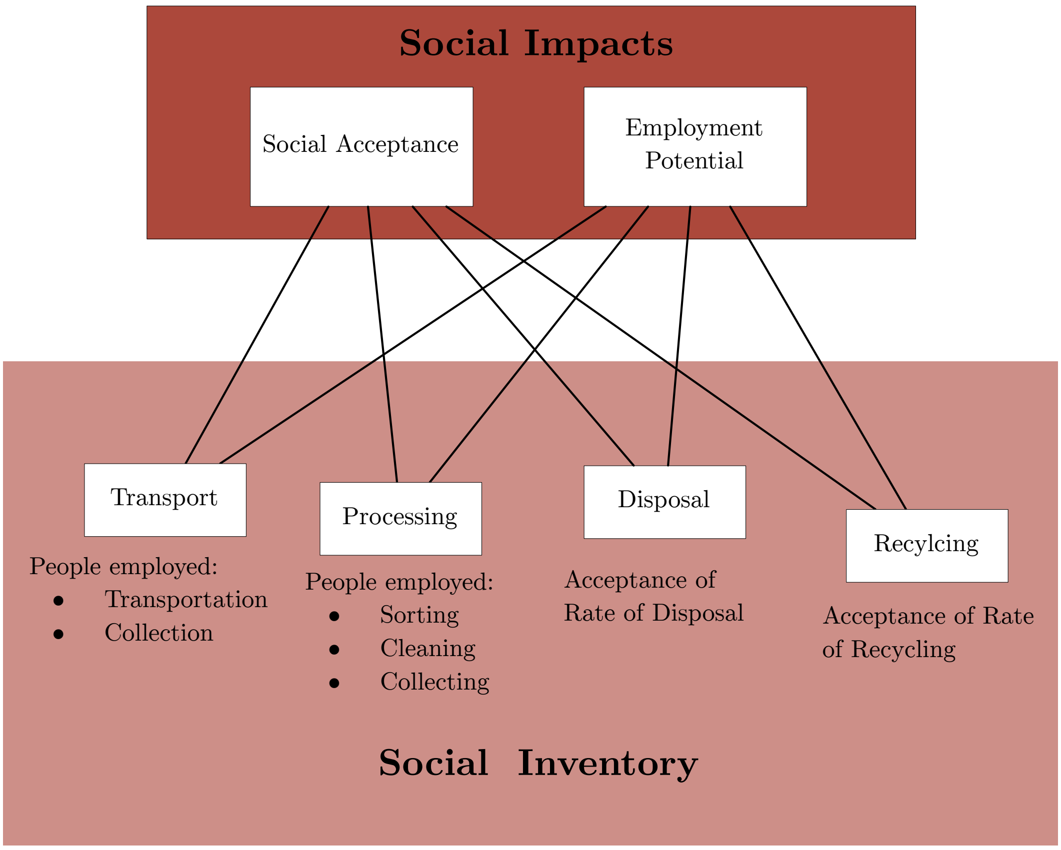


Figure 4.10: The social impact categories which have been selected in relation to the inventory data of the WMS life cycle

4.5 Stage 4 - AHP: Decision Analysis

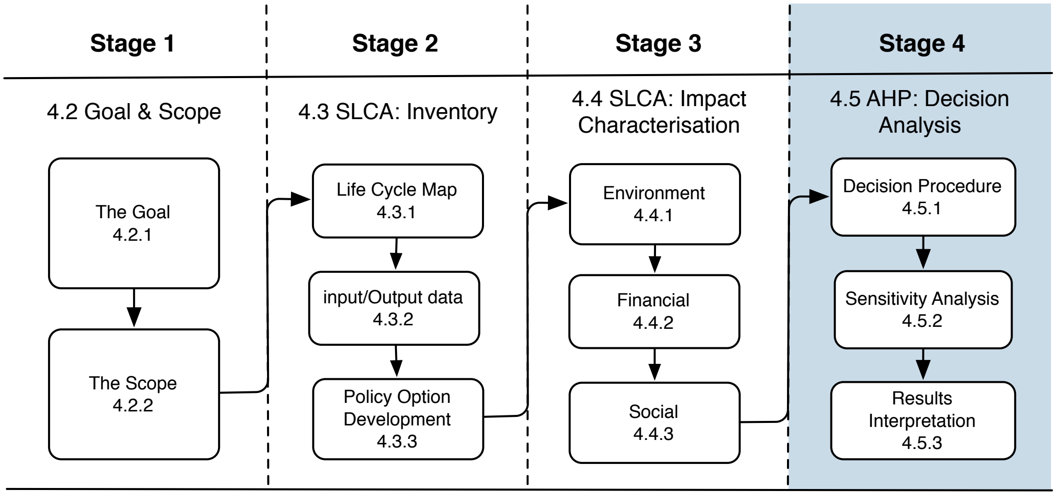


Figure 4.11: Stage 4 of decision support framework.

The final stage of the framework is shown in Figure 4.11. Using the guidelines described in Section 3.3.5 AHP was selected

The AHP method was chosen because for the following reasons:

- It allows for inputs from multiple DM.
- It can be used to organise tangible and intangible factors in a systematic way providing a structured and simple solution.
- It is suitable to finding the best alternative by using multi-parameter criteria.
- It is effective and easy to understand by decision makers.

The basic procedure for AHP was developed by Saaty (1990). It decomposes complex multi-criteria problems into a system of hierarchies. In order for the completion of a analysis, the following procedures need to be completed: create a performance matrix, obtaining weights for each object of each level, check consistency and lastly rank the alternatives (Winston, 2004).

The section focuses on determining the most viable and effective user defined WMS policy that can be applied to the SU. Figure 4.12, represents the grouping of a matrix as define by decision makers and an SLCA impact matrix that has been established through the SLCA. The two are combined and a ranking of policies is produced. The ranking allows the decisions to be made with enough information and consistent application.

4.5.1 Decision Maker Procedure

The decision makers base their decisions on the impact results that were provided by the SLCA. Other considerations include their experience and opinion on the various aspects of the policy options. Figure 4.12, represents the hierarchy framework. The hierarchy is divided into four levels, which equates to three steps (or pairwise comparisons) that have to be performed. The three steps are conducted as follows:

Phase 1: The three objectives are weighted in terms of importance to the ultimate goal of sustainability.

Phase 2: The six criteria are weighed against the three sustainable objectives. An individual criteria is only weighed against its respective objective, for *Carbon Footprint* is only weighed against environmental performance.

Phase 3: Each option is compared to every criteria, individually. This is done using consolidated impact dashboard.

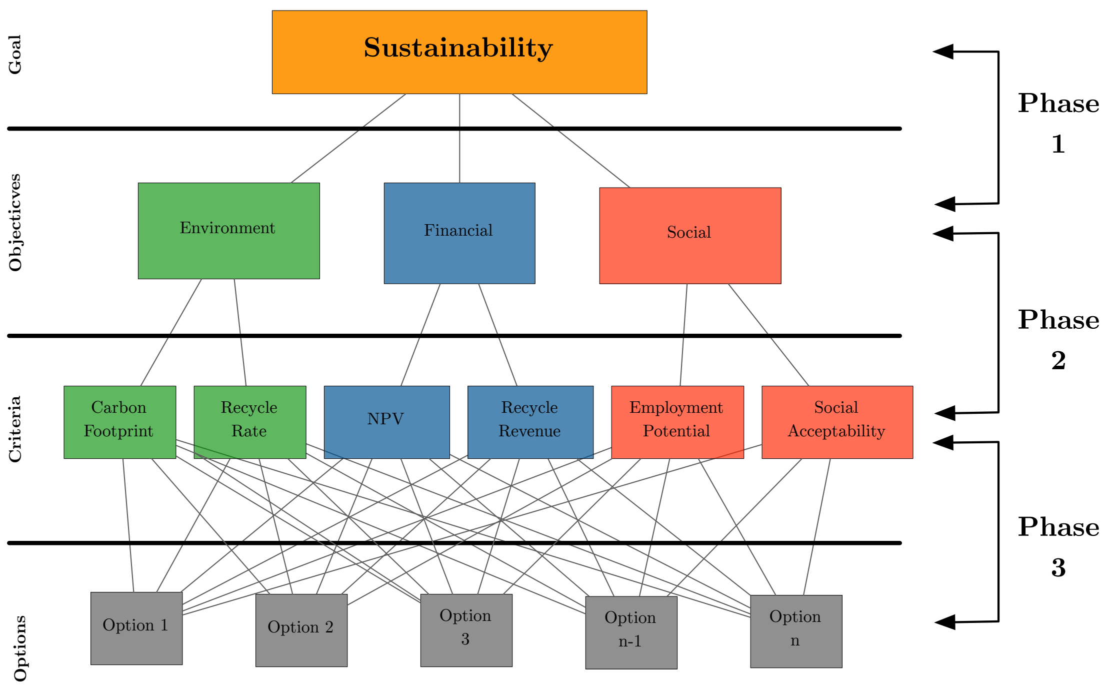


Figure 4.12: The AHP applied to a SLCA and user decision preferences

The comparisons for stage one and two are made using the decision makers own personal judgement. For stage three, the decision makers have the aid of a consolidated impact information (SLCA results) that can aid them in expressing their decision making preferences. The performance evaluation is done via the pairwise comparisons and using a consolidated impact dashboard as a reference.

Consolidated Impact Dashboard

The consolidation of results is required to put all elements of the life cycle in one place. A dashboard will be employed in the Step 3. This is so that decision makers are able to see how different policies affect the six sustainable impact criteria of the waste life cycle. An example of *Carbon Footprint* dashboard is given in Figure 4.13. Each criteria has its own unique dashboard, that has data which is constructed using five elements. These are listed below and explained in more detail.

Element 1 depicts a summarised version of results that were obtained from the SLCA with regard to *Carbon Footprint*. The graph shows the 4 elements of the impact that has been extracted; processing, transport, waste and the total.

Element 2 provides an overview of the outcomes of the policy options presented. The policy options are manually created, depending on the impact results.

Element 3 provides the weighted guide the weighted evaluation of the different. The different policy options that are kept on the sheet in order to keep decision makers mindful of what a policy actually entails.

Element 4 is explained in the following section. The weights for each step are defined by the decision makers. The other elements all aid in the completion of this element.

Element 5 of the dashboard provides a two pieces of information. The first is the Consistency Ratio (CR) which is relevant and tells the user if the comparisons and decisions he or she is making in a real time. The second is the ranking that of the different options.

Pairwise Comparisons in AHP

The decision makers preferences and consistency is a key element of the framework. The following procedure is used to gain a ranking of the different policy options under consideration by decision makers. All three steps of the AHP are conducted using pairwise comparisons. The following section briefly outlines the procedure for

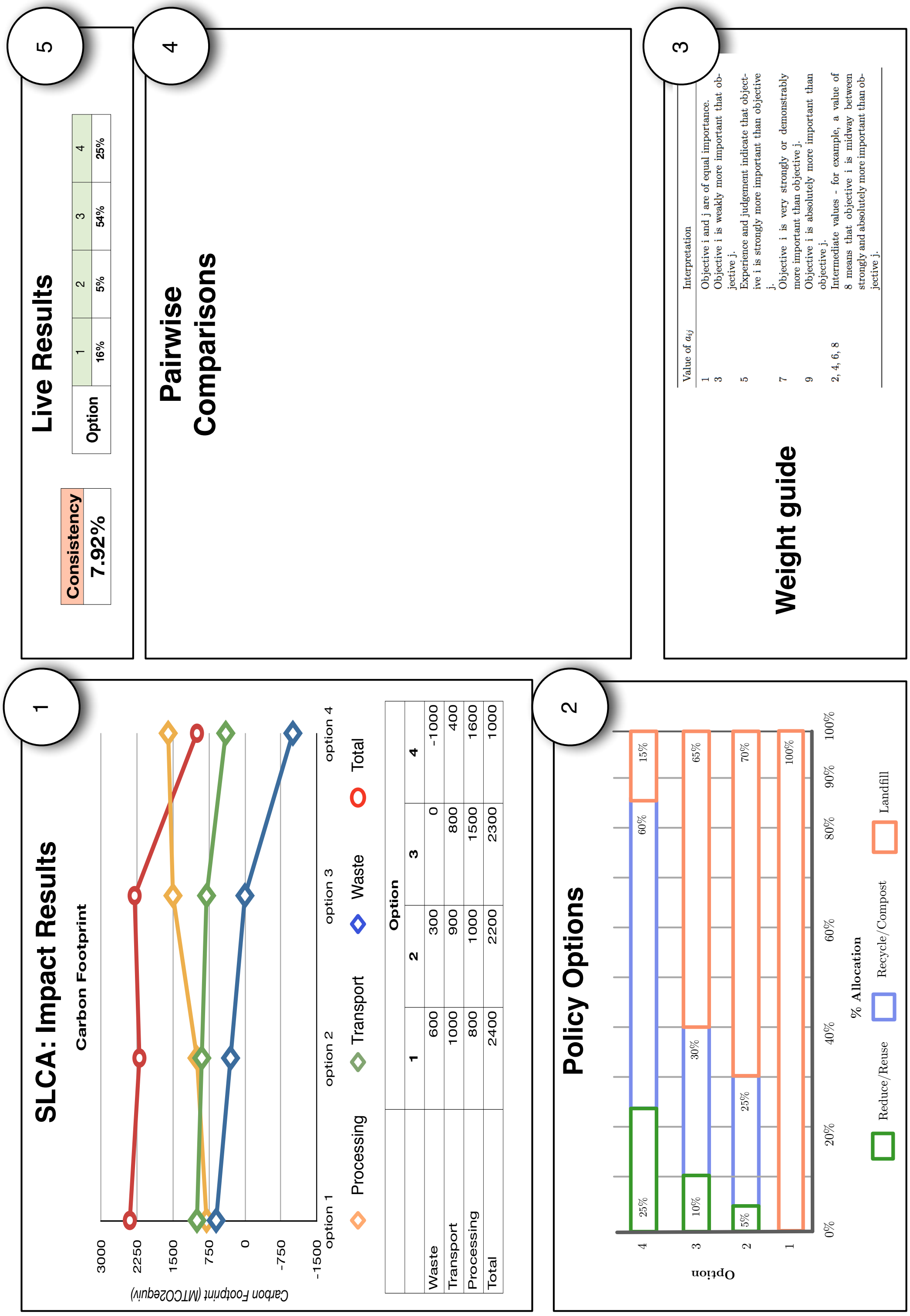


Figure 4.13: Consolidated example

Table 4.4: Interpretation of entries in a pairwise comparison matrix (Winston, 2004).

Value of a_{ij}	Interpretation
1	Objective i and j are of equal importance.
3	Objective i is weakly more important that objective j.
5	Experience and judgement indicate that objective i is strongly more important than objective j.
7	Objective i is very strongly or demonstrably more important than objective j.
9	Objective i is absolutely more important than objective j.
2, 4, 6, 8	Intermediate values - for example, a value of 8 means that objective i is midway between strongly and absolutely more important than objective j.

the ranking and measuring consistency in AHP as explained by Winston (2004).

Suppose there are n objectives that are being used. We begin by writing down a n x n matrix (known as the pairwise comparison matrix) A. From the matrix let the entry in row i and column j of A, let it be a_{ij}, indicates how much more important objective i is than j. "Importance" is measured on an integer scale valued from 1-9, with each number being interpreted as on Table 4.4. For all i, it is necessary that $a_{ii} = 1$. If $a_{ij} = k$, then for consistency it is necessary that $a_{ji} = \frac{1}{k}$.

Suppose there are n objectives. Let w_i equal the weight given to objective i. To describe how the AHP determines the w_i's lets assume that the decision maker is perfectly consistent. We will then be left with a matrix A in the form of Equation 4.1. We now recover the vector $\omega = \begin{bmatrix} w_1 & w_2 & \cdots & w_n \end{bmatrix}$ from A, using the equation Equation 4.2.

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \dots & \frac{w_n}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \dots & \frac{w_2}{w_n} \\ \vdots & \vdots & & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \dots & \frac{w_n}{w_n} \end{bmatrix} \tag{4.1}$$

Table 4.5: The values of the random index(RI).

n	RI
2	0,00
3	0,58
4	0,90
5	1,12
6	1,24
7	1,32
8	1,41
9	1,45
10	1,51

$$A\omega^T = \lambda\omega^T \tag{4.2}$$

Where λ is an unknown number and w^T is an unknown n-dimensional column vector. For any number λ, Equation 4.2 always has the trivial solution of $\omega = \begin{bmatrix} 0 & 0 & \cdots & 0 \end{bmatrix}$. It can then be shown that if A is a pairwise comparison matrix of a perfectly consistent decision maker and we do not allow $\lambda = 0$, then the only non-trivial solution to 4.2 is a $\lambda = n$ and $\omega = \begin{bmatrix} w_1 & w_2 & \cdots & w_n \end{bmatrix}$. This shows that for a consistent decision maker, the weights from w_i can be acquired from the nontrivial solution to Equation 4.2.

What if we had an inconsistent decision maker? Let λ, then be the largest number for which Equation 4.2, we can call the solution w_{max}. If the decision maker's comparisons do not deviate too much from perfect consistency then we can expect λ_{max} to be very close to n and w_{max} to be very close to w. Saaty (1990) thus proposed measuring the decision makers consistency by analysing how close λ_{max} is to n. In order to approximate the w_{max}, we can use the following two step procedure:

Step 1: For each of A's columns divide every entry by the in column i of A by the sum of the column i. This will then produce a new matrix, A_{norm}, in which the sum of every column is equal to 1.

Step 2: Find the approximation to w_{max}, the average w_i of entries in row i of A_{norm}.

Checking for Consistency

We now have to check the consistency of the decision makers comparisons. Checking for consistency is the concluding step in an AHP. It is done using two steps:

Step 1: compute the Confidence Interval (CI) as in Equation 4.3. Equation 4.4 is used in order to calculate the λ_{max}.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4.3}$$

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{i=n} \frac{\text{ith entry in Aw}^T}{\text{ith entry in w}^T} \tag{4.4}$$

Step 2: Calculate the CR, using Random Index (RI) as shown in Table 4.5, from Equation 4.5.

$$CR = \frac{CI}{RI} \tag{4.5}$$

The values for RI were constructed by Saaty (1990) and explained by Triantaphyllou (2000). The index is based on the size of the matrix, n x n. The values for Table 4.5, were calculated to give the average CI if the entries in A were chosen at random, subject to the diagonal entries equalling 1 and if $a_{ij} = \frac{1}{a_{ji}}$. A perfectly consistent decision maker has a $CR = 0$. If the $CR < 0.10$ then the degree of consistency is satisfactory but if the $CR > 0.10$ then serious inconsistencies are present and then the AHP might not yield any meaningful results.

4.5.2 Sensitivity

The sensitivity analysis is completed to see how key choices influence the ranking of policies. The sensitivity analysis for the case study will be the change in weights of the three objectives of sustainability. The weighting of the three objectives will be changed from its current situation where each objective is given an equal weight of 1, which carry the following results:

- 33.3% - Environmental
- 33.3% - Financial
- 33.3% - Social

The change of weights will be reflected in policies which reflect preferences for one objective. Thus the sensitivity analysis reflects a bias towards only one objective.

Table 4.6: Sensitivity weights

Bias	Environment	Financial	Social
Environment	**71.4%**	14.3%	14.3%
Financial	14.3%	**71.4%**	14.3%
Social	14.3%	14.3%	**71.4%**

The weights are allocated based on Table 4.4. For example, if the model were to be biased towards the financial objective, it would be given a weight of 5 and the other two objectives would be suppressed and given equal weights of 1 respectively. The weighting is thus allocated as per Table 4.6.

4.6 Conclusion

The research objective of Chapter 4 was to develop a framework that is able assess sustainability of a WMS and aid in decision making. The framework designed, consisted of 4 stages, that were set out as follows:

- Stage 1: The Goal and Scope
- Stage 2: SLCA - Inventory Analysis
- Stage 3: SLCA - Impact Analysis
- Stage 4: AHP

Stage 1 sought to clarify the intended goal and scope of the proposed framework. It is then followed by Stage 2, an inventory analysis, that was taken from SLCA, of the waste system under consideration. Once the inventory data is collected, different policy options are then developed. In Stage 3 the inventory data is then used to characterise and consolidate the selected sustainable impacts of developed policy options, also taken from SLCA.

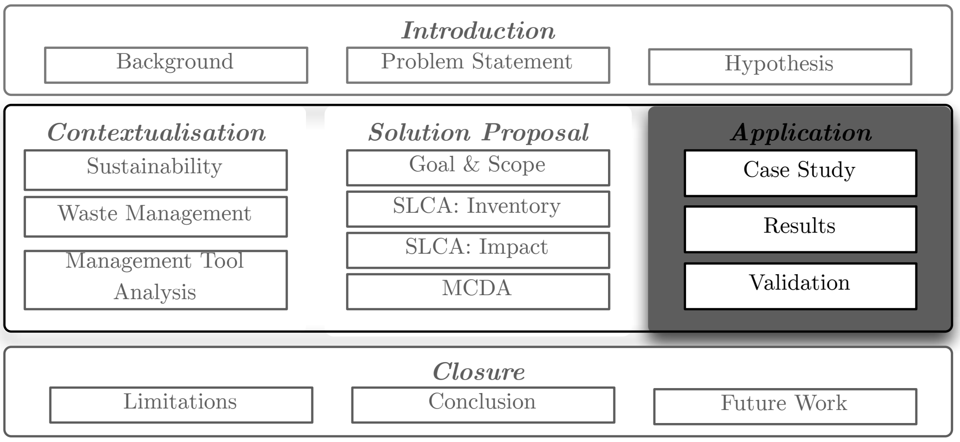
Finally Stage 4, uses the final impact results gathered in Stage 3. Stage 4, uses a branch of MCDA called AHP. AHP was selected as it offers a unique decision support tools that incorporates the experience and knowledge of decision makers. The decision makers are given a set decision procedure that offers consistency and structure in the policies being evaluated.

Chapter 5

CASE STUDY

Chapter Aim:

The aim of this chapter is to utilise the framework developed in Chapter 4. The framework is to be applied to Stellenbosch University waste management system.



Chapter Research Objectives:

⇒ ***Apply*** the framework constructed to an applicable case study.
⇒ ***Assess*** the framework outputs.
⇒ ***Validate*** the analysed results.

5.1 Getting Started

Chapter 2 found that there are multiple dimensions and objectives that can be associated in, firstly analysing and secondly deciding on sustainability within waste management. From this, two tools were reviewed in Chapter 3. LCA and MCDA were highlighted as two management tools that are capable of addressing different management silos prevalent in sustainability. A case was presented for the combination of the tools as a method for both evaluating and deciding upon the sustainability of a WMS. Chapter 4 describes the use of the SLCA/MCDA framework to aid decision makers assess and decide upon waste management policies. The framework was facilitated through the co-operation of the senior managers of SU.

The framework was constructed in order to aid decision with regard to sustainability waste management policies SU. The framework was applied and the four stages were completed. The following chapter outlines the results gained from the applied framework, that was constructed in Chapter 4. The goal and the scope of the study are outlined in detail within the Chapter 4.2. Therefore, stage 1 of the framework has already been completed.

The results that are obtained from the case study will be provided in accordance with the next three stages of the framework. Stage 2 will provide results that were obtained while gathering inventory data from the waste system. A flow diagram was completed and each inventory data for each stage of the waste management system was completed. The final step of the stage was the development of the different policy options that are to be analysed in the impact section of the SLCA.

Stage 3 is then completed through the aggregation of results obtained from the inventory data collected. The results are then consolidated and presented in a manner that facilitates decision support for the facility managers.

Finally, using the data obtained from the impact assessment, a decision analysis is conducted with the help of two University managers, who represented the Decision Makers (DM). Once the DMs completed the decision making procedure the results are discussed with regard to the three dimensions of ISWM.

5.2 SLCA - Inventory Results and Policy Development

Stage 2 of the framework allowed for the gathering of life cycle inventory data of SU's waste system. Primary data for the stage was collected from three main sources. The first data set was collected from databases of SU and the waste service provider Waste Plan. The second set of data was collected from a series of semi-structured interviews. The interviews were conducted with members of the SU facilities management, the Municipality of Stellenbosch and Waste Plan operations and management. The data was used to create a baseline waste system, that is then expanded into different waste policy options for the University.

5.2.1 Inventory Results

The inventory results of the established waste system, is an analysis based on the five life cycle stages identified, as per the methodology. Inventory data from the current system was compiled from the for the life cycle activities (storage, transportation, processing, disposal and, recycling and composting) and classified into either environmental, financial and societal data. 5.1, is the current system that has been recorded.

The map is used as the basis for the inventory analysis. It represents the life cycle stages defined in Chapter 4.3.1.

Storage

Storage data was available from University records and gave an indication of the quantity and location of municipal and recycling activities on the campus.

Two main sources of data could be obtained: the budget of SU facilities management (specifically Waste Management) and a service map of the main campus. The budget for the next 5 years was obtained and several key data points could be extracted. It included the current amount of black bins that the municipality are responsible for the relevant service fee and the service schedules. The service map provided the locations and the schedules of the black bins around campus. The map is shown in Appendix A.1, it notes the waste service locations of all buildings on the main campus (academic, residential, University services and sporting facilities)

Data from Waste Plan was obtained that indicated the types of recyclable wastes and their respective mass (not including food waste). The data is from March through to August 2012, which is 6 months and covers three seasons (summer, au-

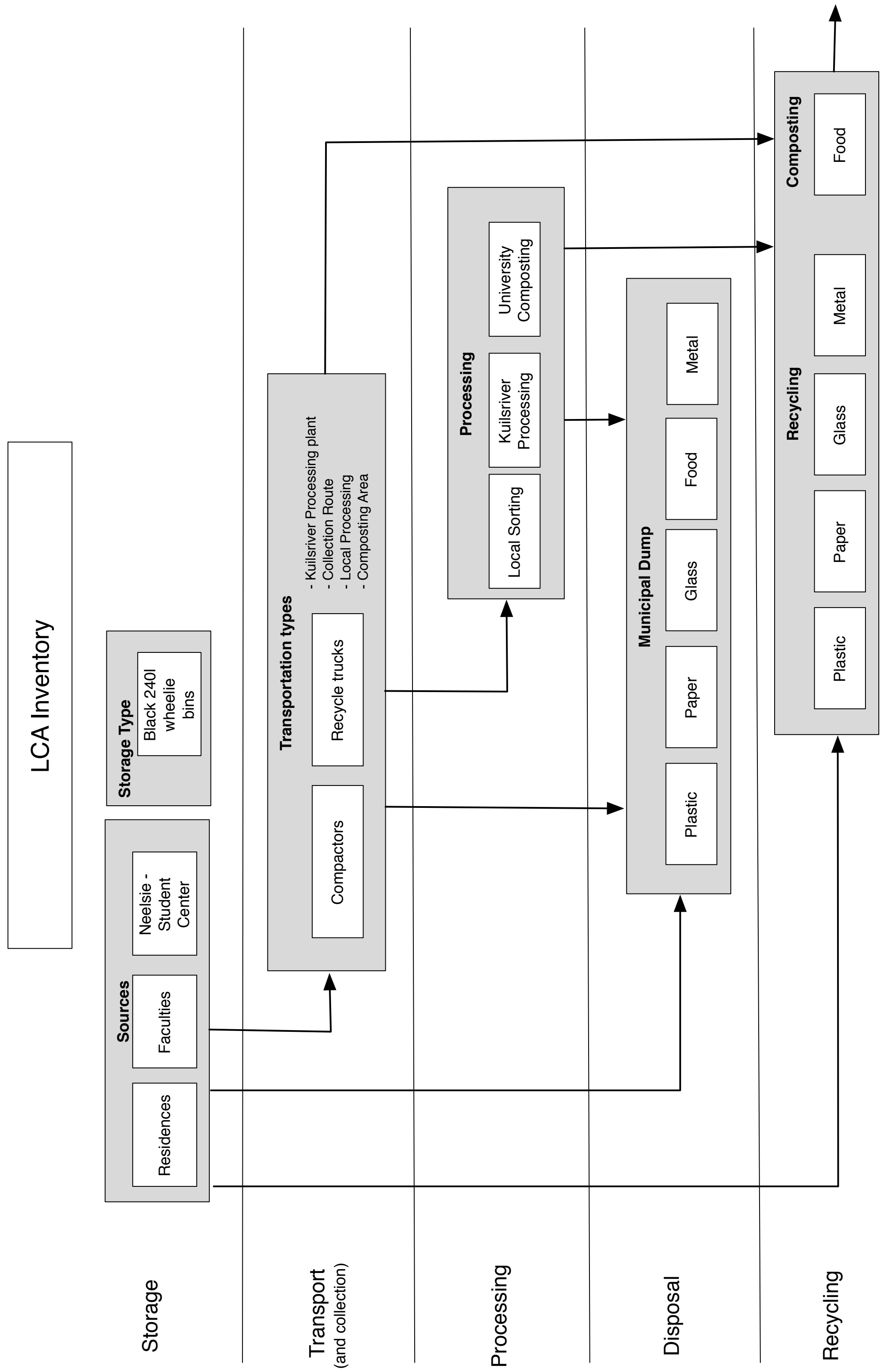


Figure 5.1: The current waste system of SU

tumn and winter) and two academic holidays (March and June-July). A continuous sample of data is therefore deemed to be large enough for the requirements of this case study.

Food waste data was estimated using the payments made for the food processing microbe *Bokashi*. *Bokashi* is used on a 1:1 scale, in other words one kilogram of *Bokashi* is used to compost one kilogram of food waste. The payment for one unit of bokashi are thus directly proportional to the amount of food waste composted.

The average weight per month was then calculated and this was extrapolated to calculate a yearly total of waste handled by Waste Plan.

It was assumed that black bins (used in the storage and collection of municipal waste) have a standard volume of $240l$, mixed waste has a density of $0.055kg/m^3$ and that each bin collected is 80% full. The assumptions were made based on waste audits conducted the Municipality of Stellenbosch. The results of inventory data for storage stage of the waste system can thus be summarised as follows:

- The total amount of waste produced by the University within a given year is 955.56 tons;
- Waste Plan handles 188 tons of waste per year from storage;
- food waste constitutes 5.6% (or 54 tons) of the total amount of waste produced by the University (collected from 20 kitchens) in a given year;
- 440 black bins are serviced by the Municipality, 400 are serviced three times per week and 40 once a week, which equates to 707 tons handled per year and.

The calculations for municipal waste disposal are shown in Table 5.1.

Table 5.1: Total amount of waste that is disposed of per year.

	Units	Full Mass	Percentage Full	Frequency (collection/year)	Subtotal	Total
Municipal Waste	400	14 kg	80%	156	684104 kg	706907 kg
	40	14 kg	80%	52	22803 kg	

Transport (Collection)

Transport data was extrapolated from the map as shown in Appendix A.1. This allowed for the yearly distance traveled to be calculated calculated.

The distances and frequency of collection by Municipality and Waste plan are shown in Table 5.2. Waste processing is conducted in two places; on main campus (where it is separated and weighed) and then transported 50km, to the waste processing facility in Kuilsriver. Waste Plan services the University all 54 weeks of the year 5 times a week. The process of waste collection is done solely by the municipality and transported to the landfill 5 km outside the town. The total route of 25 km includes all collection done at the various black bin locations around SU, as indicated on the map. All bins are processed at least once a week.

Food is collected from University Residences only. There are currently 20 residence dining halls being serviced. The food is collected by Waste Plan and then delivered to the University's farm where it is processed. The food is transported daily (during the work week) from different residences. The average distance from the residences to the farm is 2km. Currently there is only one driver employed by Waste Plan, who is responsible for the transport of both the food and recyclable waste. It was assumed that all types have the same fuel consumption over the respective distances travelled.

Processing

Processing of waste occurs on campus, in a waste sorting facility within the Langehoven Student Centre or the Neelsie. The Neelsie facility is responsible for the sorting and weighing of recyclable waste that has been collected from the different facilities, faculties and residences on campus. It is run by Waste Plan. Within the current system there are 17 people who are directly employed as sorters and cleaners. There is also a site manager in charge of the overseeing operations for the main campus.

Currently, the Neelsie facility can process a maximum of two tons of waste per

Table 5.2: Average distances waste is transported.

Route	Responsibility	Route Distance (km)	Frequency	Total (km)
Waste Processing	Waste Plan	135	270	35100
Landfill	Municipality	25	270	6750
Composting	Waste Plan	2	260	520

day. It equates to a maximum of 520 tonnes of waste that can be processed and transported per year. The average yearly waste processed is around 190 tonnes per year. The processing has an efficiency of 69.0%, which translates to 135 tonnes of waste recycled per year. The other 31% are materials that can not be recycled immediately. For the purpose of the study the un-recyclable materials are sent to landfill.

Disposal

The municipality is responsible for the majority of waste that gets taken to landfill. The municipality currently service 440 black bins at a cost of R 312.45 per bin (collected three times per week) and R88.06 per bin (collected once a week).

As calculated in the Storage stage, the municipality is responsible for 707 tons of waste disposal (waste to landfill) per year. The make up of this waste was assumed to be very similar to that which is handled by Waste Plan, because it came from the same source. Waste Plan goes through some of the waste that is destined for landfill and also extracts a certain percentage of recyclable materials.

Waste Plan provided 6 months of data. The data was then averaged over a 6 month period and multiplied by 12 months in order to get the yearly waste that goes to landfill. The total mass of waste to landfill from Waste Plan equaled 61 tons (recycling efficiency of 31%). The total mass of waste to landfill is then the sum of 61 tons from Waste Plan and 707 tons from the Municipality and therefore equals 768 tons per year.

Recycling and Composting

Waste Plan handles the majority of recycling on the main campus. Some faculties were noted to have their own recycling process, but they were not considered relevant. Waste Plan processes and weighs the recyclable waste collected from the main campus. It then gets transported to the sorting facility in Kuilsriver where the processed waste, is again weighed and only then transported to the different recycling companies. The assumption is the mixed waste might be considered *wet waste*[1]. It is therefore sorted and cleaned at the Kuilsriver facility before it can be sent to recyclers.

[1]Wet waste is defined as contaminated recyclable material. Contaminants can be usually be removed through processing and the waste can then be recycled.

The recycling activities conducted by Waste Plan were the only ones to be considered within the study. The data only deals with the waste handled by Waste Plan. The company recycled 66.7 tons of waste during the six months. It therefore translate into around 135 tons of waste per year. The table shows that the majority, 37.41% or 50 tons for a year, of recyclable materials, not including food, are categorised as mixed recyclables. The waste must therefore be processed further at the processing facility. Of the other waste types 29.31% is made up of different forms of paper, 17.35% of glass, 10.87% of plastics and the difference consists of e-waste and different metals.

SU has a program where blue bins have been placed within each dinning hall at all residences on campus. The bins are used to collect food waste. The food waste is then transported to the University farm, where bokashi microbes are then added. A process of anaerobic digestion then takes place, to break the food down into organic potable material. The digested food is then added to grass cuttings and manure and left for two weeks.

The data for composting of food was obtained from the University, in the form of bokashi amounts used per week. The amounts were logged for a 7 month period. The amount of bokashi used is always equal to that of the food. This allowed the calculation of the food recycled within residences.

5.2.2 Translating Inventory data into an Impact Analysis

This section provides a connection between the inventory data that has been collected and the impact analysis to be concluded. It further explains how the respective policy options have been created for SU WMS. Figure 5.2, designates the manner in which the identified inventory data will be assigned to the selected impact categories. The figure represents the five stages of the WMS. The impacts associated with the different inventory results are as follows.

Environment Results

Environmental impacts can be associated with all five waste management activities. Firstly, the recycling rate of the given system was found to be highly dependant on the type and quality of the waste being disposed. Thus storage and the initial disposal of waste has a major impact on recycling. The sorting efficiency, conducted by Waste Plan, is the last line before materials are transported to be recycled.

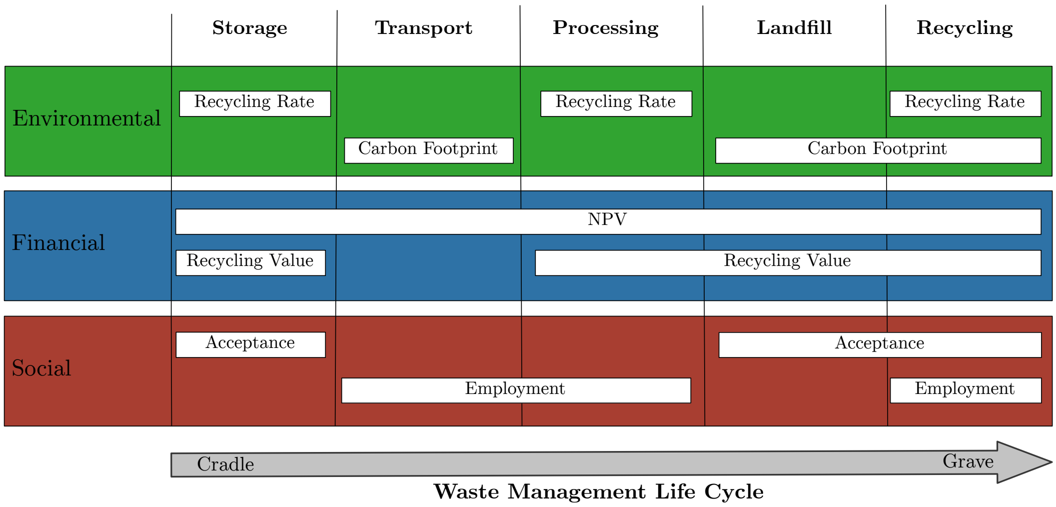


Figure 5.2: The resulting impacts as identified in the inventory analysis

Secondly, the transportation and then landfilling or recycling of waste, was identified as major sources or sinks of *Carbon Footprint*. For transportation, the distance and efficiency of the vehicle were recorded. Next, the type and mass of waste affects the amount of $CO_2equiv.$ that are released over the time frame measured.

Financial Results

Financial inventory was addressed by two impacts as indicted in Figure 5.2. The inventory data was sourced from three different operational role players, namely:

- Stellenbosch University - Composting
- Waste Plan - Recycling and Landfill
- Stellenbosch Municipality - Landfilling

The *NPV* of the studied WMS was affected by each of the life cycle activities, as all three role players are present during one or all activities. Due to confidentiality agreement, with one party, the costs and income of the different activities were not isolated. Thus only the total NPV is represented.

The *Recycling Value* of the given waste was calculated from the amount of recyclable waste which entered the system and could potentially be extracted for recycling. The amount of waste, types and mass of the recyclable waste sorted was used and then multiplied by the respective prices per kilogram. A complete list of recyclable material prices are represented in Appendix A.3.

Social Results

Employment Potential was affected by three activities of the studied life cycle. From Figure 5.2, *Employment Potential* was identified in the transportation, processing and recycling activities.

Socially, the *Acceptability* of a given waste option was based only on the evaluation of the policy options finally developed in Chapter 5.2.3. It can however be stated that the *Acceptability* of a given option is dependant on whether waste is disposed, recycled or reduced.

5.2.3 Option Development

From the inventory results, 10 different waste management options were created. The options use the data extrapolated from inventory and will be used to calculate the impacts on the three elements of sustainability.

The specific plan was established from the baseline scenario as depicted by the inventory results. From the results it was noted that 80% of the waste within the

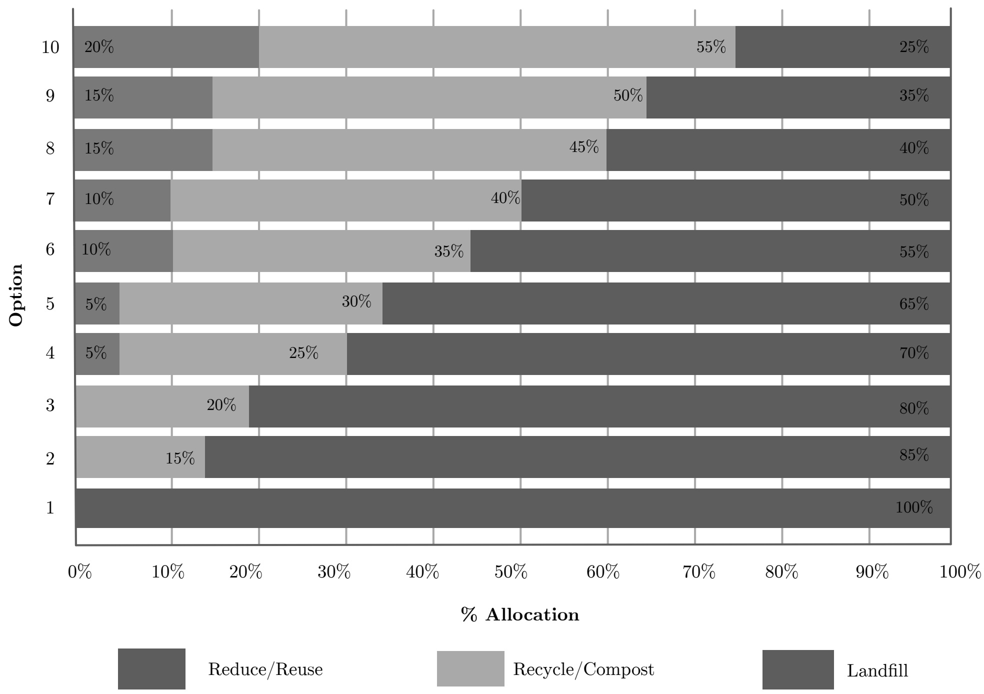


Figure 5.3: Developed policy options.

system was being directed to landfill and 20% was recycled. Option 3, represents the current waste management policy. The options are progressively scaled according to the waste hierarchy. The options are represented in Figure 5.3. Every option is considered under the same service conditions (One Scenario) as the baseline. The options were selected using the waste contractors and capacity within the University. They are created according to the waste hierarchy as directed in the framework and example in Section 4.3.3. The contractors that were identified include:

- Reduce/Reuse - Stellenbosch University and Waste Plan
- Recycle and Composting - Stellenbosch University and Waste Plan
- Landfill - Waste Plan and the Municipality of Stellenbosch

The first policy option is for no waste to be recycled and all waste to go to the landfill. This option is undertaken using only the municipality of Stellenbosch as a service provider. The second and third options rely on three parties, namely SU services, Waste Plan and Stellenbosch Municipality. The waste management practices occur on a very limited scale.

From options 4 to 7 a progressive increase in waste reduced and waste to recycling is selected. The reduction in waste can be contributed to education and awareness campaigns driven by the University. The increase in waste directed to recycling, requires a greater service levels from the internal (SU for composting food waste) and external (Waste Plan for handling recyclable waste). The key element in increasing the rate of recycling, is to increase the opportunity for stakeholders to sort waste at source, i.e having different bins available for different types of recyclable waste so that it is easy for sorting (of the different types of waste) to occur at source.

Options 8 through to 10 were selected as the extreme point or outer limit of the current scenario . There is a limited role to be played by the municipality, as only 40% to 25% of waste is directed to landfill. This would require 60% to 75% of all waste to be either avoided (reduced/reused) or to be recycled. Reduction and recycling activities would therefore require an extreme level of compliance by all stakeholders of the SU. Compliance from the stakeholders would be interpreted as strict values of reduction and recycling are practiced by all stakeholders.

5.3 SLCA - Impact Results

The next stage is the presentation of impact results that were derived from the inventory study and the policy options the were developed. A full set of impact results are presented. The SLCA used the data aggregated during the inventory analysis. The impacts were measured across the life cycle, for every stage of the waste system.

The environmental inventory provided insight into the first criterion *Carbon Footprint* of the University. The major impacts were identified during the transport, disposal and recycling elements of the waste system. The second criterion *Recycling Rate* was derived from the waste data provided by Waste Plan. The rate was only defined as the final step of the waste management system.

The economic impacts focussed on the overall costs incurred for a given option. The third, *Net Present Value* (NPV) of the different options was used as a method of comparing the present worth of the different options that were presented over a five year period. Criterion four, *Recycling Rate* represents recycling and composting activities. It is focused on the economic value of waste at the end of the waste management cycle; disposal and recycling.

The social life cycle had impacts on the transport and processing of waste as it moved trough out the system. Waste *Acceptability*, criterion five, is a function of how different stakeholders accept the policy options considered for the waste system. The sixth and last criterion, *Employment*, represents the potential impact on employment for the different policies to be evaluated.

5.3.1 Environmental Impacts

The environmental assessment selected reflects environmental performance of the given waste system. The two measures selected to define the impacts on the environment. The first was the *Carbon Footprint*, the second the *Recycle Rate*.

Carbon Footprint

The first impact to be analysed is *Carbon Footprint*, which is measured for one year. Key elements identified during the waste life cycle include the composition of waste and the distances travelled. The elements affect the amount and type of processing, disposal, composting and recycling, that in turn affect the $CO_2 equiv.$ of the life cycle of a specific option.

From Figure 5.4, it can be noted that there is a general decline in the $CO_2equiv.$, moving from option 1 through to 10. Figure 5.4, displays the impact of three aspects namely:

- emissions released from only waste,
- emissions released from transportation and
- emissions across the waste life cycle.

The options range from having a large amount or all waste going to a landfill, to having the majority of waste being recycled and reduced, and the minority of waste ending up on a landfill. For the analysis conducted on only waste (green line), this accounts for a near linear drop, in emissions from waste, as the progressive options are analysed. Option 1 releases 2000 $MTCO_2equiv.$ per year, a major global warming impact. When compared to option 10, which is a carbon sink, more emissions are prevented than are being emitted. It therefore results in negative emissions of nearly 500 $MTCO_2equiv.$ per year. A stagnation in the reduction of green house gases occurs at 4 and 5 where levels remain at nearly 2500 $MTCO_2equiv.$

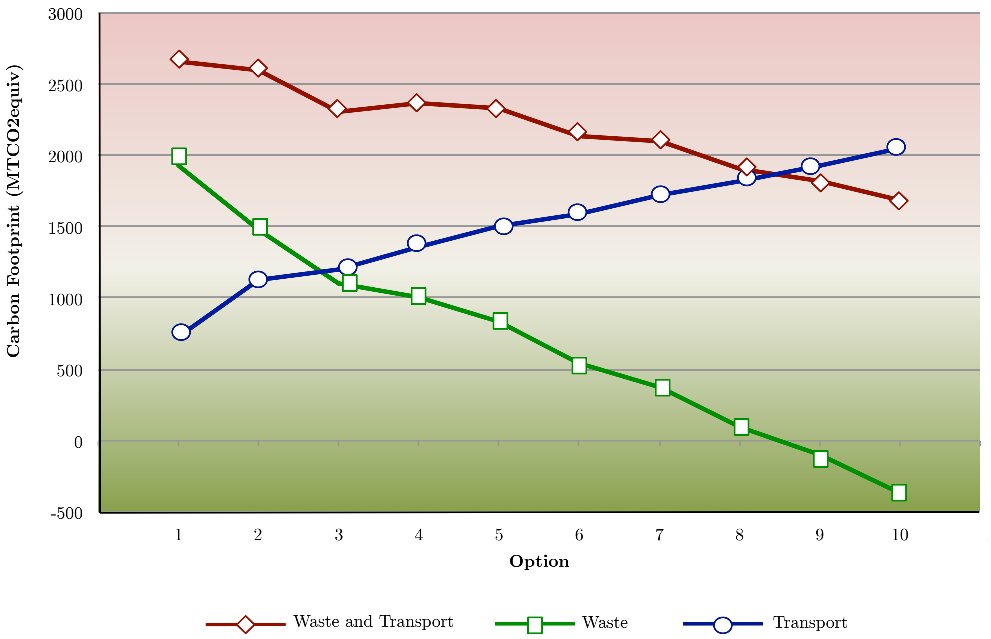
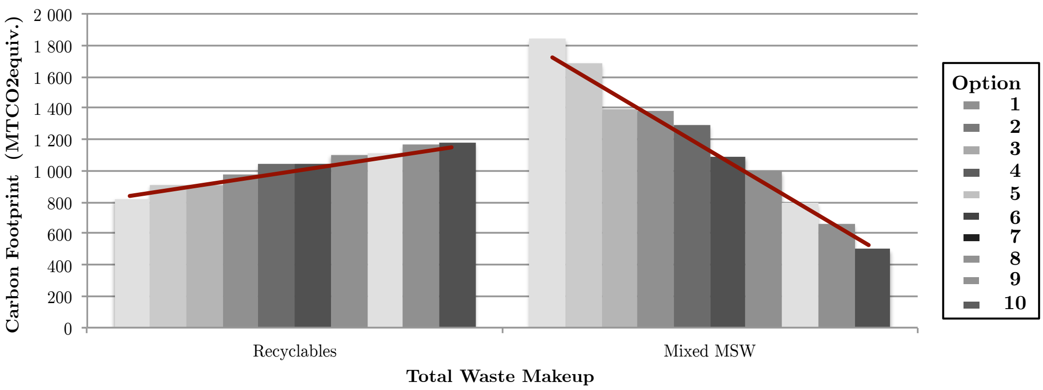


Figure 5.4: The comparative view of the *Carbon Footprint*

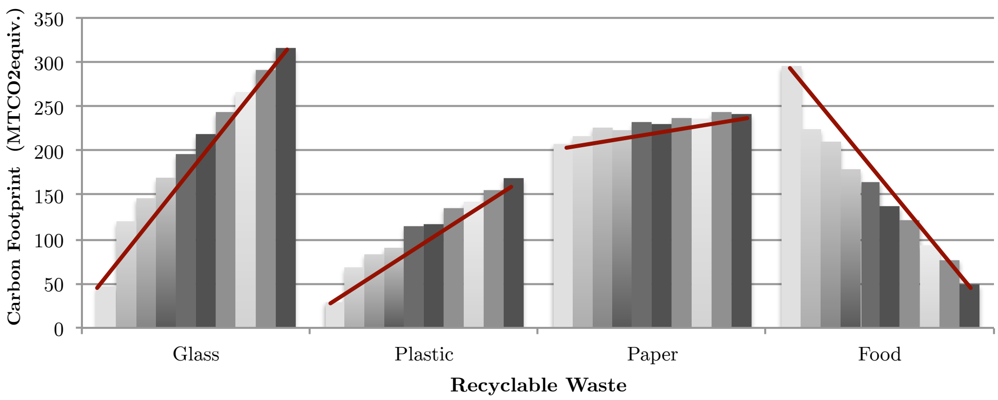
The downward trend is however offset by a notable upward trend in the *Carbon Footprint* of transportation (blue line). As options become more recycling intensive the greater the distance that vehicles have to traveled in order to get recyclable material to processing stations and collected from the various collection points around the University. The current baseline (policy option 3) indicates that transport is slightly larger source of green house gasses than waste, causing 1203 $MTCO_2equiv.$.

Overall there is a general decline in the $MTCO_2equiv.$ across the outcomes of the of options 1 to 10 was noted. It shows that by decreasing waste inout and increasing the amount of waste recycled andequates to a decrease in the global warming impact of the University waste system.

Going on step further in the details of the why $MTCO_2equiv.$ emissions decrease.



(a) General and recyclable waste MT$CO_2equiv.$ emissions



(b) Specific recyclable waste MT$CO_2equiv.$ emissions

Figure 5.5: Waste categorisation and related *Carbon Footprint*.

One can note the Figure 5.5a, that shows the greatest decrease relates more to the waste being removed from landfill and instead being recycled. A very strong downward trend is prevalent in options that have less waste ending up on waste. This is despite the fact that $MTCO_2equiv.$ emissions increase (at a much slower rate) as more recycling is done.

The ideal situation is the one where carbon emmissions are at its lowest possible levels, as in option 10. This is a decrease of 26%, from 2301 $MTCO_2equiv.$ to 1681 $MTCO_2equiv.$ per year. With a closer look at the emissions rise for recycling materials in Figure 5.5a, the biggest reduction in GHG is from the diversion of waste form landfill and not recycling as would be assumed. Levels are reduced from 1800 $MTCO_2equiv.$ per year to just under 500 $MTCO_2equiv.$, which is a dramatic reduction. Figure 5.5b shows the biggest green house contributors were plastics and glass. This again can be attributed to the distances that have to be travelled in order to recycle waste. The opposite is true for food waste because of the much smaller distances that have to be travelled to compost the food waste.

Recycle Rate

As an operational measure, the *Recycle Rate* of the University deals with the amount of waste that is recycled for each option. The impact is dependant on the efficiency of processes that are recycled by Waste Plan and the amount of waste that goes to landfill.

The core findings within this *Recycle Rate* impact are shown in Table 5.3. It

Table 5.3: The *Recycling Rate* and Efficiency

Option	*Recycle Rate*	Efficiency
1	0.0%	
2	27.7%	Low
3	35.2%	
4	43.7%	
5	50.1%	
6	58.02%	Medium
7	63.5%	
8	71.0%	
9	75.6%	High
10	82.69%	

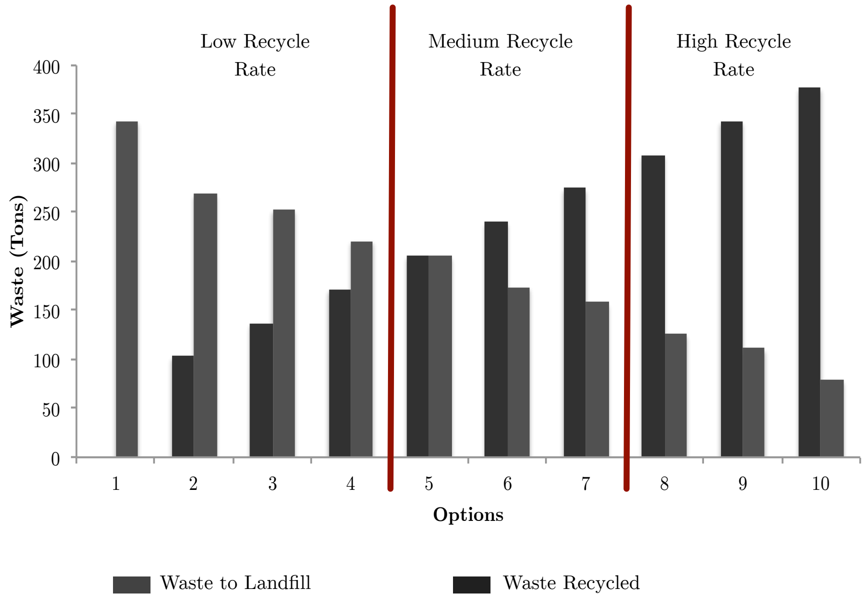


Figure 5.6: The comparative view of *NPV*

show clear increase in the recycling efficiency that needs to be achieved.

The results for the recycling study required the input of the efficiency of the current waste management system and the efficiency of waste being separated. At present option 3 is the most representative of the current system. It represents a small fraction (35 %), of the possible waste that is still available to be recycled. The current options therefore represent a low rate of efficiency.

As the recycling outcomes of the options increase, a direct, relationship can be derived. Figure 5.6, represents the amount waste that needs to be recovered from the waste system. From options 5 to 7, a transition between the amount of waste recycled and the waste to landfill, 50.1% to 63.5%.

Options 8 through to 10 represent recyclable waste that is within the system, between 300 to 400 tons of need to be directed towards recycling. Thus Waste Plan would need to ensure that they are able to sort and transport the equivalent recyclable waste for a given year. As the options have been established, massive emphasis would have to be placed on education and improving the internal efficiency of recycling waste. The waste generators, namely staff and students, would have to be the main drivers of waste to recycling.

5.3.2 Financial Impacts

The financial impacts that were drawn from the inventory data focus on three elements. The first was the impact the different strategies would have on the University over a 5 year period. The second was the revenue that could be generated from the recycling that took place.

NPV

The *NPV* was used to measure the financial expenditure of the waste system over a 5 year period. This data was sourced form the University and sheds light into where the waste expenses are mainly focused.

The main cost centres were identified as the Stellenbosch Municipality, Waste Plan, and food processing (Composting). These are represented in Figure 5.7. The values have been scaled, at the request of University administration because of sensitive information relating to contracting companies. Figure 5.7, indicates an increase in costs as options begin to progress towards reduction and recycling intensive waste

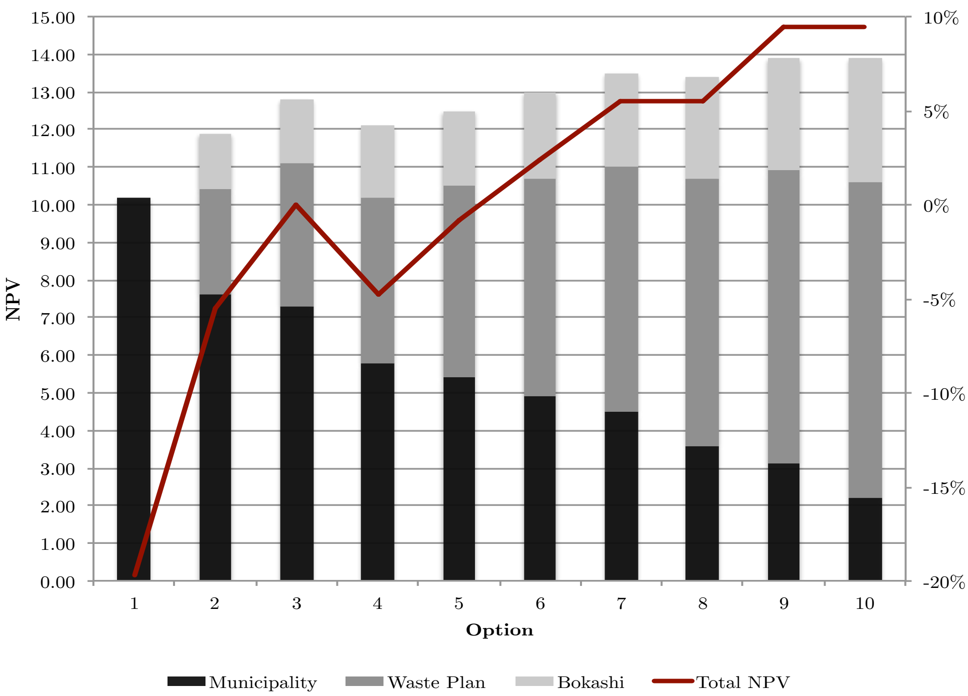


Figure 5.7: The comparative view of the *NPV* of the different options

management systems. An exception can be noted in options 4 and 5. The two options were the first to include source reduction of at 5%. The reduction would account for the reduced factored *NPV* by 9% and 1% respectively, as indicated by the red line graph.

The municipality, who are in charge of removing black bins, account for the highest costs for option 1. Option 1, is a zero waste management option. All waste is taken to landfill. The costs are directly related to the amount of Wheelie bins that the municipality services per week. With the greater reduction and recycling rates, associated with options 2 to 10, a clear downward trend can be observed in costs allocated towards the municipality.

As a contractor Waste Plan is responsible for managing waste for the University. The current contract is over a 5 year period. From Figure 5.7, the value of the contract is represents a scaled *NPV* of around 40% of the total NPV for the current waste policy. For the scenario analysed, the options assume the progressive use of Waste Plan, as the main service provider of the University in order to drive recycling. Option 4, shows an 8% drop in the *NPV* from the baseline, this is due to a greater emphasis on waste reduction. The reduction in waste is also reflected in the number of black wheely bins in the system. The municipal bill has been reduced by 26%, and this accounts for the large decrease in total *NPV*. There after the *NPV* of the options increase almost linearly until option 7, plateau and jumps in value to the most expensive options: 9 and 10. Waste Plan therefore become the dominant cost centre from option 5, taking over from the municipality.

Composting, can be equated to the cost of processing food. The composting is done internally by the University's forestry department. The cost includes the bokashi microbes (Used to anaerobically digest food) and labourers. All other costs were assumed to be absorbed by the University, this includes maintenance and running costs of any machinery used.

Over the 5 years the value of bokashi composting will be a factored *NPV* of 1.6, using the current baseline. The main contribution of composting is the bokashi enzymes. Therefore, the more food that gets recycled the more the enzymes to break the food down. The cost of composting is heavily dependant on the amount of food being processed. Costs therefore rise as the respective options increase the amount of waste recycled/composted. Option 10 is there for the most expensive option at a factored *NPV* of 3.2 and option 2 the 1.6.

Recycling Value

Recycling Value, is one of the key aspects that one can derive from the waste management system. Although it is generated by the University, it does not directly benefit revenue generated from recycling, because revenues generated are part of Waste Plan's contract. The value of waste was accounted for over a year. The measure provides an idea of the value of the waste that is being thrown away and that can be generated through recycling activities.

From Figure 5.8, it can be seen that the there is a general rise in the value of waste which is in the system, this is despite the fact that there is less waste in the system. The rise in value can be attributed to the quality of waste which would be disposed of. The quality of waste improvement is due to the education and awareness.

The total value gained through recycling efforts increases linearly, from R 0 in option 1 to just under R 250 000 in option 10. The result can be attributed to the growth in value from recycling and is lost from landfilling, for option 1 to 10. The recycling and composting rate can directly affects the value of waste that is recovered. The greater the rate, the greater value to be extracted from the waste stream.

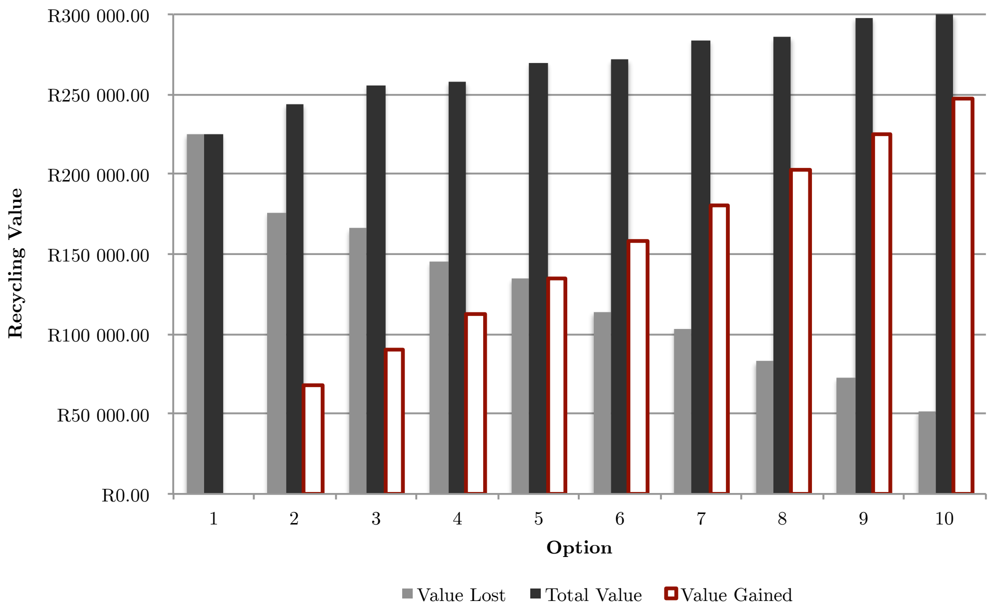


Figure 5.8: The value of recycling for a give year.

It can be noted that option 10 has the most value that can be directly drawn from the waste system of the University at nearly R 300 000 per year. Only R50 000 worth of recyclable and compostable material is being sent to landfill. This figure is nearly three times the amount that is currently being realised in the baseline option. The baseline indicates that the value of waste that is going to landfill is still more than twice the value at R160 000 per year.

Figure 5.9 depicts the second side of the story. The pie graph shows an aggregated breakdown of the different types of recyclable waste. The linearity between the different policy options with the regard o the value of waste that is produced by SU. As can be concluded from the figure the greatest amount of value can be recovered from the plastic materials. It constitutes more than 40% of the value for any given option and more than double any other type of waste. In terms of value for option 10, this would mean R 102 000 in revenue that could be generated from plastics alone, as shown in Table 5.4. The table indicates that the volume of waste recycle makes a large difference in the amount received. It pays to recycle more.

The indicator provides insight in the potential value that can be extracted from a waste system. The value that is gained from the recyclable waste sold can be used to fund the increased price of executing a more preventative and recycling intensive policy option.

5.3.3 Social Impacts

Social impacts were divided into two criteria as described in the Chapter 4. The social sustainability is constructed using three concepts with waste management. The system should be seen as acceptable, equitable and functional. Acceptability and equitability were the two areas that were actively measured and described among the alternative waste management options that were considered. Equity of the waste

Table 5.4: The value of waste for options 3, 5, 8 and 10

Option	3	5	8	10
Glass	R 16193	R 24290	R 36435	R 44531
Paper	R 19815	R 29722	R 44583	R 54491
Plastic	R 37321	R 55982	R 83973	R 102634
E-waste	R 898	R 1346	R 2020	R 2469
Food waste	R 13465	R 20197	R 30296	R 37028
Metal	R 2407	R 3610	R 5415	R 6619

system is measured in the *Employment Potential* offered by a given policy and acceptability was directly measured from stakeholders of the waste system.

Employment Potential

The first results to be presented are the equitability of the suggested options. Equitability is measured in the *Employment Potential* a particular option may have. Only direct employment of the waste system was considered relevant towards this study. This therefore disqualified work created outside the set boundaries of this study. This included employment at waste disposal and recycling facilities. Although, the municipality does employ people who directly work with the life cycle. They were not considered as they would have been hired regardless. This was because of the scale of operations and the large size of other areas which the municipality also services.

The information that was used consisted of interviews and employment data from the main waste contractor of the University and the University Facility Management. The data was mainly qualitative in nature and so the scale of data used was used to represents this. Two main employers were identified: SU and Waste Plan. Waste Plan employs workers in sorting, transport and weighing processes. The University

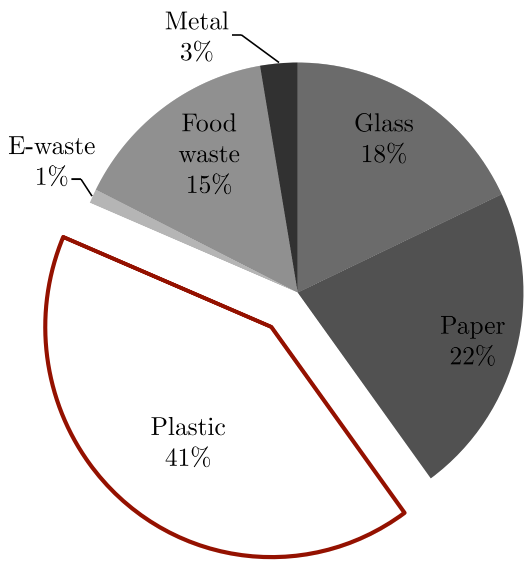


Figure 5.9: The value of waste per category

employs persons in the recycling activity of composting. The work was created as a direct result of waste management system of the University.

From the Figure 5.10, it can be seen that the greatest *Employment Potential* is created from the baseline option that is already in use. Option 1, presented with the smallest amount of direct employment because no direct labour could be contributed as no recycling or composting activities took place. Options after the baseline presented with a steady decrease in the amount of *Employment Potential*. This despite the amount of waste that was either being recycled or directed to be composted. This is explained because of the dynamics at play, within the reduction/recycling/composting intense options.

The greater reduction and recycling options rely on the waste separated at source. It would the mean that less sorters would be required on campus, as the options move progressively towards greater recycling. Composting activities is a contributor towards job creation, specifically towards the people on the University farm that

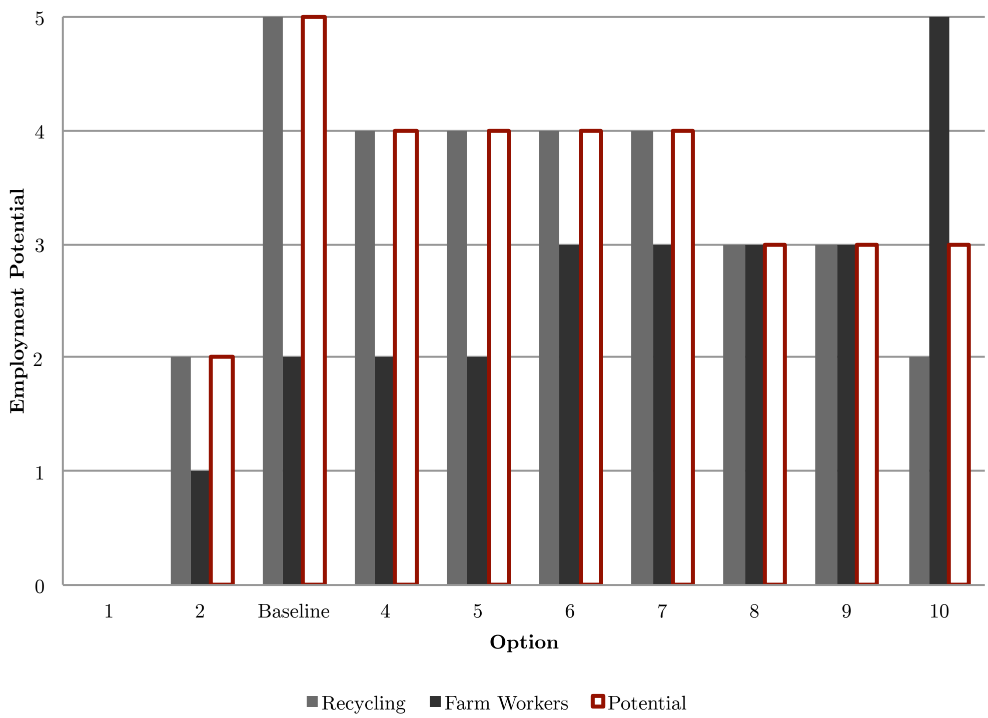


Figure 5.10: The employment opportunity that exists for the options presented.

Table 5.5: The acceptability rating for the different options.

Option	1	2	3	4	5	6	7	8	9	10
Rating	2.0	2.4	2.9	3.9	4.4	5.3	5.8	7.2	7.7	8.6

work on composting. The more food waste that is diverted into composting the more *Employment Potential* the option has. Combined, however recycling still contributes the majority of employed persons. That is why the greatest *Employment Potential* remains the current baseline option.

Acceptability

Acceptability of the different waste management outcomes is representative of how acceptable a given waste policy was for stakeholders.

The study was conducted across the campus and a total of 44 responses were received. It was an illustrative study in how stakeholders can be represented in an analysis around waste management options. The respondents were categorised into: Post-graduate, under-graduate, academic and service staff. The categories represented the majority of stakeholders that represent Stellenbosch University. The respondents were represented by:

- Undergraduate Student - 31 (68.9%)
- Postgraduate Student - 10 (22.2%)
- Lecturers - 2 (4.4%)
- Service Staff -2 (4.4%)

It represents a small sample of stakeholders of the University.

From Table 5.5, it can clearly be seen that the options 8, 9 and 10 have the favoured options that were selected by the different stakeholders. Options from 1 to 4 are by far the least preferred by stakeholders.This can be seen as an understanding that the most preferred solutions are those that accept the reducing and recycling are important factors for stakeholders and that sending our waste to a landfill is no longer acceptable practice.

As this is only an illustrative study, the results can only be used as a general guideline about the attitudes people have towards what happens with their waste.

5.4 Decision Analysis Results

The decision analysis was structured around the key decision makers and facilitated a consistent and effective decision making framework. The decision making processes was followed, as defined in the stage 4 of the framework. The framework allows a decision hierarchy of the different policy options to be created, and this is represented in Figure 5.11.

The decision hierarchy was used as the skeleton for the decision process. Firstly, the consolidated impact dashboard was presented to decision makers. This was done to ensure that decisions can be made, knowing their respective impacts. Secondly, they decision makers were asked to complete the three phases of the framework's Analytical Hierarchal Process (AHP), in other words; give weights to objectives, options and criteria. Thus giving a complete view of the decision makers preferences with regard to the alternatives, the criteria, the objectives and the ultimate goal of sustainability. The final step is an aggregation of the results into a single ranking of the options.

5.4.1 Pairwise Comparison

The decision hierarchy constructed in Figure 5.11 is an integral part of the decision making processes. The hierarchy is made of four levels: options, criteria, objectives and the goal. Six options were selected that were then evaluated against the six selected impact criteria. Individual criteria represented respective objectives. The objectives then served the ultimate goal. The options that were selected are: 2, 3, 5, 6, 8 and 10. Each option was selected as it showed a favourable result in one or more of the impact criteria. Options 2 and 3 were selected as they have the greatest impact with regard to the social criteria of *Employment Potential* and the lowest possible *NPV*. Options 5 and 6 were selected because they were considered intermediaries, (or options which have a balance between the respective criteria). Finally, options 8 and 10 were selected because they represent the best results in terms of environmental impact. Both *Recycle Rate* and *Carbon Footprint* were the highest and lowest rates respectively.

One of the key concession that had to be made was that a group meeting with the different stakeholders could not be arrangement after numerous attempts. Therefore individual sessions were conducted with two of the three key members of facilities management. By conducting the two decision analysis procedures separately, the average of the scores for objectives, and criteria were averaged in order to obtain the

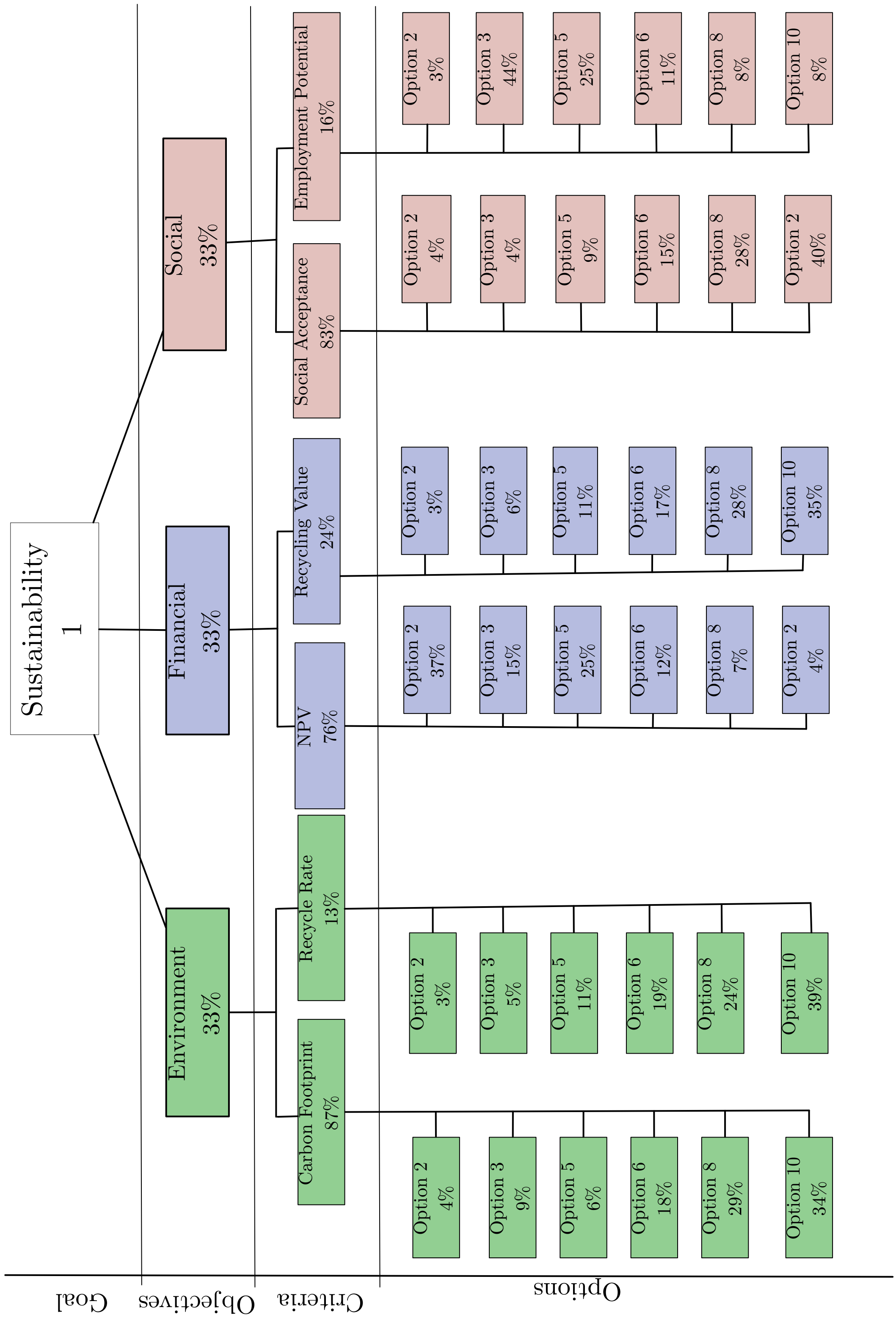


Figure 5.11: The decision hierarchy and respective results

final results. The two members are:

- John de Wet - Senior Technical Manager: Stellenbosch University Facilities Management

- Meg Pittaway - Grounds Manager: Stellenbosch University Facilities Management

This procedure was kept straightforward and simple, when conducting the analysis with each DM. The three phases were conducted as per the framework design. Based on the decision makers' experience and judgement the AHP was completed. The results were presented as a percentage and ranked accordingly. The higher the percentage the greater the preference for a particular selection. The decisions were continuously checked, live feedback was provided during the process. As recommended by Triantaphyllou (2000) and decided in the Chapter 4.5.1, a Consistency Ratio (CR) level of less than 10% was always required.

Phase 1 - Objectives vs. Goal

Assessing the three objectives against the ultimate goal of sustainability is the first pairwise comparison to be undertaken. The results were merely a formality as only three comparisons needed to be completed. From Table5.6, it can seen that all options were preferred equally for both candidates. Thus the weights given to criteria in terms of each objective will be the deciding factor in the selection and ranking of a particular policy option. It was a simple comparison to complete and thus the CR of the decision was 0%.

The results indicate that through the initial phase of the analysis, the decision makers regarded all three of the sustainable pillars as equal. For the rest of the AHP, the weights allocated to the individual criteria will therefore the critical in order to establish the results.

Table 5.6: Results for the objectives and options pairwise comparison

Sustainability		
Objective	Ranking %	CR
Environment	33.3	
Financial	33.3	0.0%
Social	33.3	

Phase 2 - Criteria vs. Objectives

Phase two involved evaluating the importance of the selected criteria against the objectives. The criteria of the three objectives were compared against one another. Three straight forward pair wise comparisons, were conducted. There were only two criteria per objective.

Carbon Footprint, *Recycle Rate* were ranked by the decision makers as stipulated in Table 5.7a. The rankings of the criteria show a very strong preference for the *Carbon Footprint*. *Carbon Footprint* was weighted with a score of 87% which states a strong preference above the *Recycling Rate* (13%) of a given option.

Financially, *NPV* and Recycle return were tabulated as per Table 5.7b. The top criteria was selected as the *NPV*. A preference of 76% of was given. It indicates that the *NPV* is very strongly preferred. The *NPV* provides an overall picture of the value of the current and other potential options which was more important to decision makers *Recycling Value*.

The social preferences of the decision makers was closer than the other objectives. Table 5.7c shows the *Acceptability* of the waste system was marginally more important when selecting between the criteria. *Employment Potential* was given a score of 46% compared with the *Acceptability* rating of 54%.

Table 5.7: Results for the Environmental criteria and options

(a) Criteria evaluated against the financial objective.

Environment	
Criteria	Ranking %
Carbon Footprint	87
Recycling Rate	13

(b) Criteria evaluated against the environmental objective.

Financial	
Criteria	Ranking %
NPV	76
Recycling Value	24

(c) Criteria evaluated against the social objective.

Social	
Criteria	Ranking %
Employment Potential	46
Acceptability	54

Phase 3 - Alternatives vs. Criteria

The six alternatives were then compared individually against each specific criteria. The results for each criteria were tabulated and the CR of the decisions were also included and iteratively concluded until the CR was below 10%.

The results for the environmental evaluation are summarised on Table 5.8. From the evaluation of the *Carbon Footprint* it can be seen that a strong preference was made towards options 6, 8 and 10. Option 2, 3 and 6 were by far the least desirable options. Option 10, produced the smallest *Carbon Footprint* and it was thus the most desirable option from a decision makers perspective.

The second evaluation with regard to the *Recycling Rate*, the same emphasis was placed on options 6, 8 and 10. The recycling performance was a again the largest for these options. Option 10, highlighted in Table 5.8 is expressed in the results as 13 times more favourable than option 1, and it 15% more desirable than its nearest option (option 8).

The next evaluation of criteria, was financial performance against the six options. Table 5.9 summarises the decision results. For *NPV*, the option results were heavily

Table 5.8: Results for the environmental criteria and options

	Carbon Footprint		Recycling Rate	
Option	Ranking %	CR	Ranking %	CR
2	4	5.19%	3	9.73%
3	7		5	
5	6		11	
6	16		19	
8	28		24	
10	38		39	

Table 5.9: Results for the financial criteria and options

	NPV		*Recycling Value*	
Option	Ranking %	CR	Ranking %	CR
2	36	2.01%	3	3.70%
3	17		6	
5	25		10	
6	11		17	
8	7		29	
10	4		35	

in favour of option 2. The option had a desired ranking of 37%. The option was also the top performer with the lowest *NPV* of the waste system. Option 5 had the second lowest *NPV* and this also resulted in the decision makers preference as the second most desirable option. The other options had relatively low ranking scores and were therefore not considered to be attractive. Options 8 and 10 have ranking scores of only 7% and 4%, respectively.

The *Recycling Value* results from the LCA results showed that option 10 was the best performer and there was a linear relationship, decreasing in value for option 8 through to 2. The ranking preferences and the results showed a similar trend as option 8 and 10 were the top ranked options. The two options had respective ranking scores of 29% and 35%.

The last evaluation, considered the social criteria and the six options. The six options were evaluated against the ability to provide employment and the acceptability of the waste system options.

The *Employment Potential*, as shown in the first column of Table 5.10, of the systems showed that the baseline option, option three, outperformed the others. This was translated by the decision makers as ranking preference of 44%, nearly 20% greater than option 5 which was in second place. Options 2, 8 and 10 were the most unattractive prospects, within the options. The scores reflected this point as all had a ranking score of 8% and less.

The *Acceptability*, in the second column of Table 5.10 results indicated that a system which has high levels of recycling and waste reduction were the most desirable for stakeholders of the University. The decision makers affirmed the results of the study and ranked option 8 and 10 as the most attractive options. The baseline

Table 5.10: Results for the social criteria and options

	Employment Potential		*Acceptability*	
Option	Ranking %	CR	Ranking %	CR
2	3	8.78%	4	8.90%
3	44		4	
5	25		8	
6	10		15	
8	9		26	
10	8		42	

(option 3) and option 2 shared last place with a ranking of 4% each.

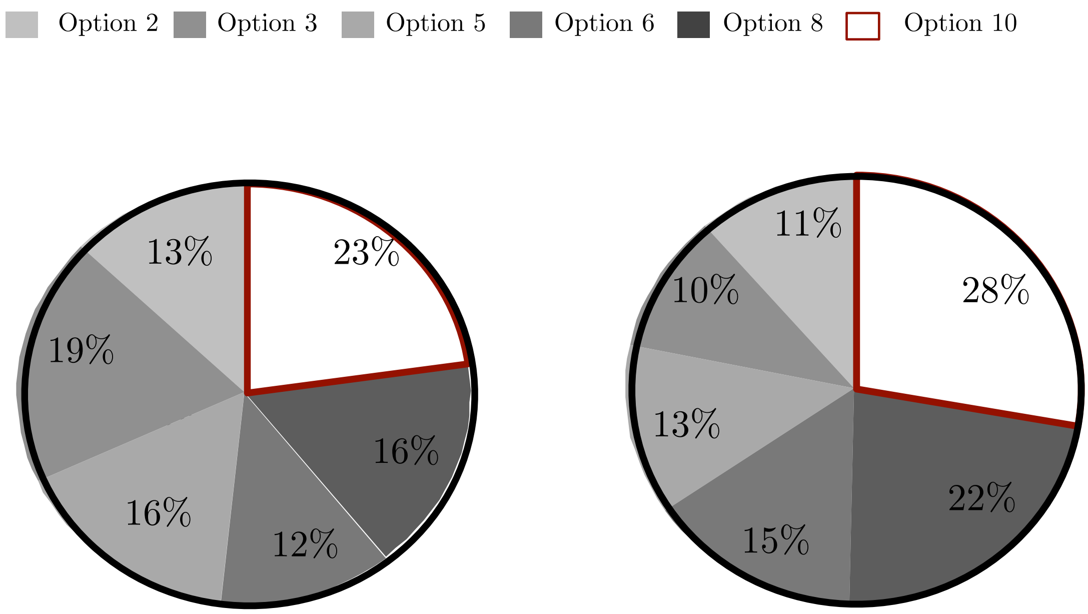
The CR of the decisions for all criteria fell within the desirable range and were therefore represented valid and consistent decisions.

5.4.2 Making the Decision

Finally the results of the pairwise comparisons can be synthesised based on the results of the pairwise comparisons of the options, criteria, and objectives of the decision framework. Firstly Figure 5.12 , represents the views of the two decision makers that aided in the framework. Lastly, Figure 5.13 represents the final aggregation of the results for the AHP followed by the management staff of Stellenbosch University.

AHP Result

The results of the two decision makers assessed are represented in Figure 5.12. The differences in the results of the two makers are distinct. The results from the analysis conducted with Meg Pittaway represent a relatively even distribution between the options presented. Option 3, the current WMS, and Option 10 were the most preferred with rankings of 19% and 23% respectively. John De Wet's results represented



(b) Meg Pittaway (c) John de Wet

Figure 5.12: The decision results for the individuals assessed

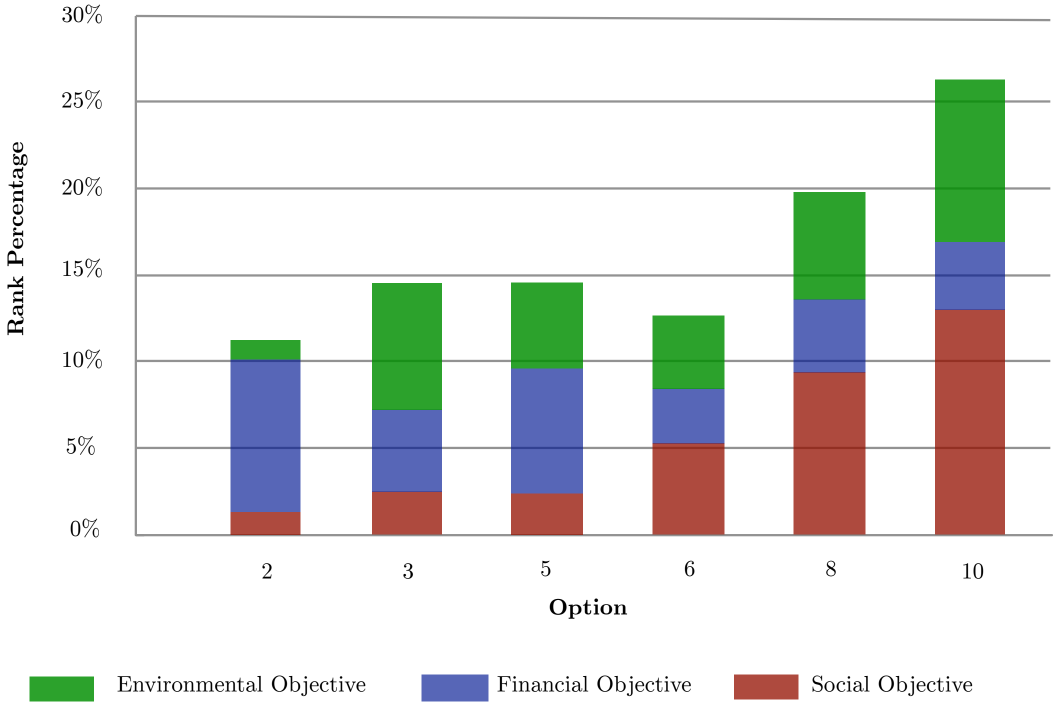


Figure 5.13: Decision Analysis Results

a more distinct preference for options 10 and 8. The largest difference in the results can be attributed to the weights assigned to the Social Impacts. Meg Pittaway had a preference for the *Employment Potential* above the *Acceptability*, with a ranking of 75% against 25%. The opposite preferences were expressed by John de wet who preferred *Acceptability* rather than *Employment Potential*, with a ranking of 84% against 16%.

The final ranking is represented in Figure 5.13. The results from the information gathered from the decision makers resulted in a single ranking of the six options. One option stood out against the other five. Option 10, was the stand out option and achieved the best overall ranking, with 27% and option 8 had the second highest ranking with 21%. The high ranking can be attributed to the high performance of two criteria; *Acceptability* and *Carbon Footprint* which the decision makers valued highly and thus performs very well for the two options. The criteria both carried significant weight within their respective objectives, *Carbon Footprint* with 67% and *Acceptability* with 83%.

NPV was a criteria that reflected contrasting results within the financial objective. The decision results for *NPV* were heavily in favour of options 2, 5 and to a smaller degree option 3, which had lower value over 5 years. The financial performance of option 5 dramatically increased it's ranking although it sacrificed in terms of environmental performance.

From the options covered in the analysis, the decision makers concluded the option 2 was the least desired option, with a ranking percentage of only 12%. Options 3, 5 ended up in the middle of options the average ranking just below 15%. Option 6, was the second last and performed weakly in the AHP in financial and environmental preferences of the decision makers. Lastly, option 8 and option 10 were regarded as the best two policy options by decision makers.

Sensitivity of the AHP

A sensitivity analysis was conducted, by introducing a variation in the weights assigned to the objectives. The weights were changed by giving an single objective a score of 5, which equates to a ranking of 71.4% against the other two and making the other two objective equal to each other by giving them a score of one or a ranking of 14.3% each.

Firstly, the environmental objective was selected and biased against the financial and social objectives. The financial and social objectives were considered almost equally important and given a score of 1. The results show that Option 10 is preferred by a 6% margin above option 2. By placing greater emphasis on the environment, the performance of the *Carbon Footprint* criteria determines greatly the which option is preferred. In this respect option 10 outperformed the others.

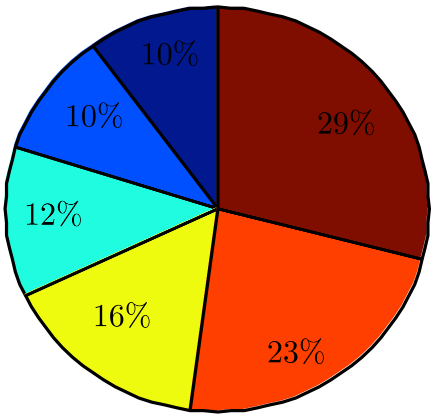
Next, the financial objective was weighted against both the social and environmental objectives. The results show an extreme shift in the opposite discretion, from the AHP results. The preferred option remains number 10, with a ranking score of 23%, followed by option 8 with a score of 19%. Option 2, then ranked third with a score of 17%. The shift can mainly be attributed to the high weight placed on the *NPV* criteria, which was strongly in favour option 2, which was the cheapest.

Lastly, the social was weighted strongly against the environment and financial objectives. The results are very similar to both the results in Section **??** and environmental objective preference results. Option 10 and 8 are again the two most preferred options with scores of 22% and 29%. *Acceptability* of the waste system is the most influential criteria within the social objective. The *Acceptability* was strongly in favour of option 10 and least favoured option 2. Option 6, is then in third place due to its strong preference in the social criteria that were assessed.

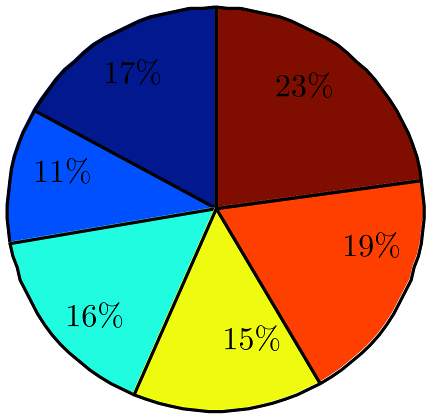
Overall, the sensitivity analysis provided an strong indication that policy option 10 still provided, according to the decision makers, the greatest amount of benefits. The decision makers are willing to pay the sacrifice the extra amount of money in order to improve the social and environmental objectives.

5.5 Validation

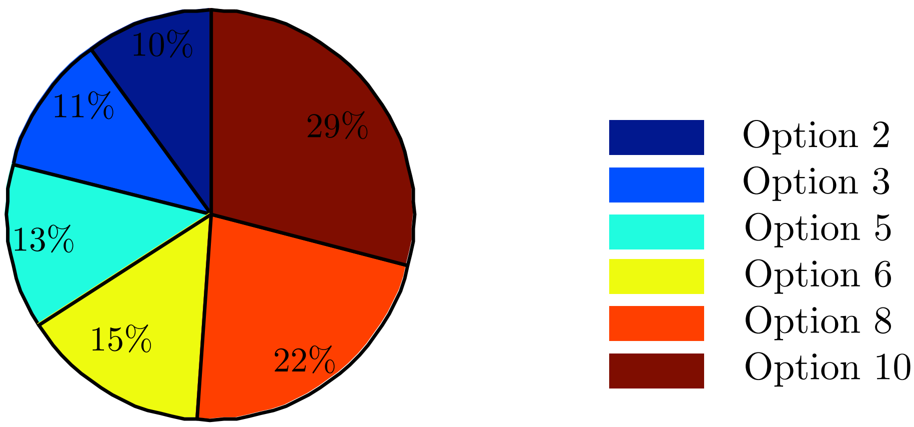
Validation has been separated into two sections. The first addresses the validity of the established framework as a means to gather and interpret sustainable data on



(a) Biased towards the environmental objectives.



(b) Biased towards the financial objectives.



(c) Biased towards the social objectives.

Figure 5.14: The results from a sensitivity analysis of objectives.

waste management. The second concerns the validation of results that were obtained from the decision makers.

5.5.1 Framework Validation

The framework was developed in order to provide decision makers, in charge of managing waste systems, an opportunity to explore the effects of their decisions on sustainability. Firstly, the framework used an SLCA as a basis to gather and interpret the defined impacts of the sustainability. Secondly, the multi-criteria decision analysis tool, AHP, was used to aid in decision making. It was used to express DM preferences and support the selection of the most appropriate policy option.

On the first count, the SLCA portion of the framework, the inventory results gave a satisfactory view of the current waste system. The results were then expanded and impacts were calculated for the various policy options created. The framework presented acceptable impact results, that could be evaluated and compared across different options, as was originally intended by the framework design.

For the second count, validation of the decision making process, constitutes the last part of the framework. Its aim was to facilitate and assist decision makers, in interpreting results and making consistent and suitable decisions. The framework was conducted with the aid of two facility managers of SU. Consistency is a massive factor in the decision making process. This lead to multiple iterations of the AHP process with decision makers in order to get consistently accurate results. They were directly displayed and rankings were obtained.

5.5.2 Result Validation

Two steps were involved in validating the results obtained from the case study. The first step involved validation of three items: life cycle mapping, inventory data collection and impact analysis. It was done by presenting the previously stated items to the two facility managers: Meg Pittaway and John de Wet. The managers were satisfied with the process and results produced by the developed framework.

Secondly, the decision making processes was fully reliant dependant DM input. Live feedback was provided as the decision making processes was conducted. The feedback provided consistency and ranking results. Upon completion of the decision analysis, discussions were held concerning the results and their relevance. The results fitted well with the preferences expressed by the respective decision makers.

Through validation of results the decision makers felt that the insights provided by the framework in both current policy impacts and the impacts that future policy decisions may have on sustainability of the waste management system.

5.6 Conclusion

The case study that was conducted on the waste management system of SU. The case study targeted the impacts that the University has on sustainability. Three types of impact categories were noted as per the three pillars of sustainability. The framework that was developed in Chapter 4, was used in the assessment and decision support of the a new waste management policies. The first research objective of the chapter was thus completed; the framework developed in Chapter 4 was applied to a case study.

The first stage of the framework was completed as in Chapter 4.2. It finalised the goal and scope within which the framework would be constructed and executed. The second stage included the analysis of inventory results and the development of policy options. Through the application of this stage, basic inventory results could be obtained. The results included a basic knowledge of current waste management system and relevant sustainable inventory. The penultimate stage was the impact analysis, as a part of the SLCA. Six impact criteria were classified and characterised from the policies and inventory results of stage two. The impact criteria allowed for a look into the three pillars of sustainability and how high level decision making affected each of the individual categories. The final stage (Stage 4) of the framework involved the application of decision support, using AHP. A decision tree was constructed, the results of the different sustainable criteria were presented from stage 3 of the framework. Members of the University's facilities management were then asked to use the tool in deciding which factors were important and by how much more they were important.

Through the completion of each stage of the framework, the assessment of the outputs completed the second research output.

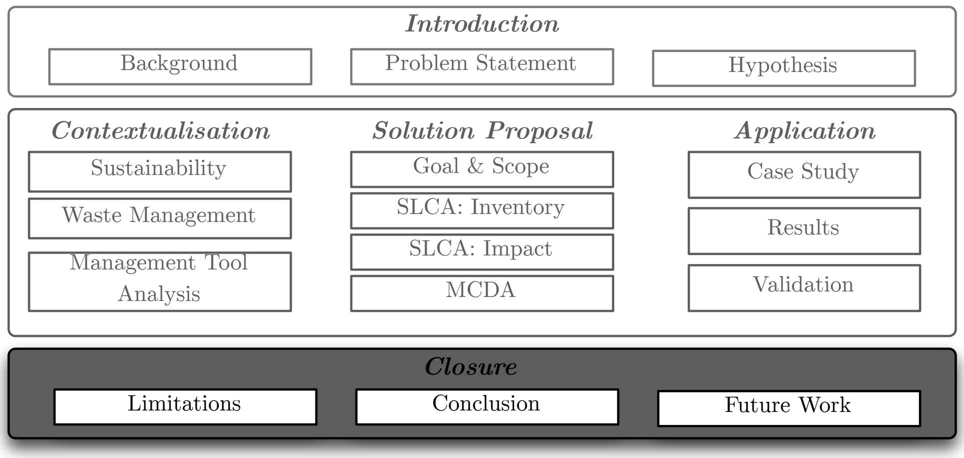
The final research objective validates the framework that was applied. Two forms of validation were undertaken. The first validated the framework that was constructed in Chapter 4. Through the successful execution of each stage of the framework, the framework was validated. The second validation, investigated the results obtained from the framework. The results were discussed with decision makers within the University and were satisfied that the results obtained from the SLCA and AHP portions were valid and provided valuable insight into current and potential future waste management policies. The final research objective of the chapter was thus completed.

Chapter 6

Closure

Chapter Aim:

The aim of Chapter 6 is to provide an overview of the thesis and provide closure to the results and research conducted. Additionally, this chapter points out the limitations of the study and states recommendations for future work for sustainably managing Stellenbosch University's waste system.



aleph **Chapter Outcomes:**

⇒ ***Review*** the work conducted in this thesis.
⇒ ***Highlight*** the limitations of this study.
⇒ ***Provide*** a final conclusion and answer the research question
⇒ ***Recommend*** work for future research.

6.1 Review

Stellenbosch University (SU) has committed itself to becoming an institution that promotes sustainability. The waste that is produced is therefore subject to the same principle of sustainability. The role of decision making within waste management is therefore crucial and must be able to factor the multiple criteria that are relevant to ISWM. Chapter 1 of the study introduces a broad outline of the thesis along with the problem statement and hypothesis.

Chapter 2 consisted of the two primary research topics that were integrated in this thesis. The topics of sustainability and waste management were reviewed in detail. Sustainability was described in the context of human development, in other words sustainable development. The terms are generally defined by the three pillars of environment, social equity and the economy. Many definitions were discussed and a final definition was selected. Brundtland and Khalid (1987) was selected and they defined sustainability as the development that meets the needs of the present, without compromising the ability of future generations to meet their own.

The focus then shifted to the topic of waste management. The section highlighted the different elements within a waste system. The topic of integrated waste management was then discussed. The focus then shifted back to sustainability, but with waste management. The last section of the chapter move on to the different tools that aid in policy decisions regarding sustainability within waste management. CBA, LCA and MCDA, were briefly assessed as viable alternatives that could be used to construct a framework supporting sustainable decision making. LCA and MCDA were then selected as options that require further investigation.

Based on the conclusions drawn from Chapter 2, LCA and MCDA were selected as tools that could be used to build the framework. Chapter 3 was a detailed study on the two decision aiding tools. The tools were analysed in terms of their application to a waste management and sustainability. LCA was found to provide a suitable tool to generate sustainable inventory data and complete an impact analysis. It lacked the basic decision making structure for the decision support framework. By comparison MCDA gives structure and consistency for interpreting data but was lacking in terms of gathering and synthesising data. It was decided that an integrated model would present a suitable method for gathering, synthesising and deciding upon a waste management policy.

The policy framework developed in Chapter 4 therefore presented an integrated tool that uses LCA and MCDA. By applying the two tools and using sustainability as a basis, a full framework was completed. The construction of the framework included 4 stages. The first three stages were derived from SLCA and the last using AHP.

In validating the use and applicability of the framework, a case study was conducted on Stellenbosch University. The case study was coordinated with the aid of University Management. The framework was used to decide upon sustainable waste management policies.

6.2 Limitations

In combining LCA and MCDA to create a sustainable decision making framework, some key limitations were noted. The limitations are stated explicitly below.

i. *Data*: The type of data collected limited the type and scope of the analysis that could be conducted. Better data would ensure a fairer comparison between alternatives.

ii. *Sustainable Knowledge*: Knowledge concerning the application of sustainable waste management is a key stumbling block within facility managers. The emphasis of waste management has always been to reduce costs and improve operations thus limited the framework's current application.

iii. *Paradigm Shift*: Based on the previous point, a shift in the thinking which governs traditional waste management must occur. The impact of decisions are not yet considered to their full extent.

iv. *Waste Management*: By design, waste management is an unsustainable field, as the creation of waste is not sustainable in the long run therefore the sustainability of a waste management system is limited.

The limitations have set the path for conclusions to be made.

6.3 Conclusion

The research question asked wether LCA and MCDA could be used to create a helpful framework that can improve sustainability within waste management. Based on the research, case study execution and case validation, the framework based on the integration of the two tools does provide improved decision support to managers. This answers the research question posed in Chapter 1, and thus rejecting the null hypothesis. A decision support framework that is based on SLCA and MCDA can provide a basis for improved decision making within sustainable waste management.

6.4 Future Work

The conclusion rejected the null hypothesis. From the research conducted and the experience gained, the areas of recommendations for future research encompass the following four suggestions:

i. *Criteria*: The criteria selected as part of the study is only a handful of sustainable metrics that can be extracted for use in the assessment and decision making of a waste system. Future studies may look at the type of criteria required for different waste systems in other areas.

ii. *Operational Decision Support*: The next logical step of sustainability within waste management would be to incorporate an operational decision framework. On the basis of the final results obtained from this thesis, future studies could incorporate efficiency and effectiveness indicators for operations, such as processing and transport.

iii. *Framework Execution*: The thesis showed that creating a framework that is able to tackle four aspects of ISWM: Environmental, Financial, Social and Policy. Two other aspects namely political and technical aspects can still be addressed. The two aspects need to be investigated in terms of executing the framework.

iv. *Expanded Framework*: The work conducted in this thesis was limited by the type of data obtained. Future work could incorporate an expanded list of impacts that could be used to assist in covering all operational levels of an organisation.

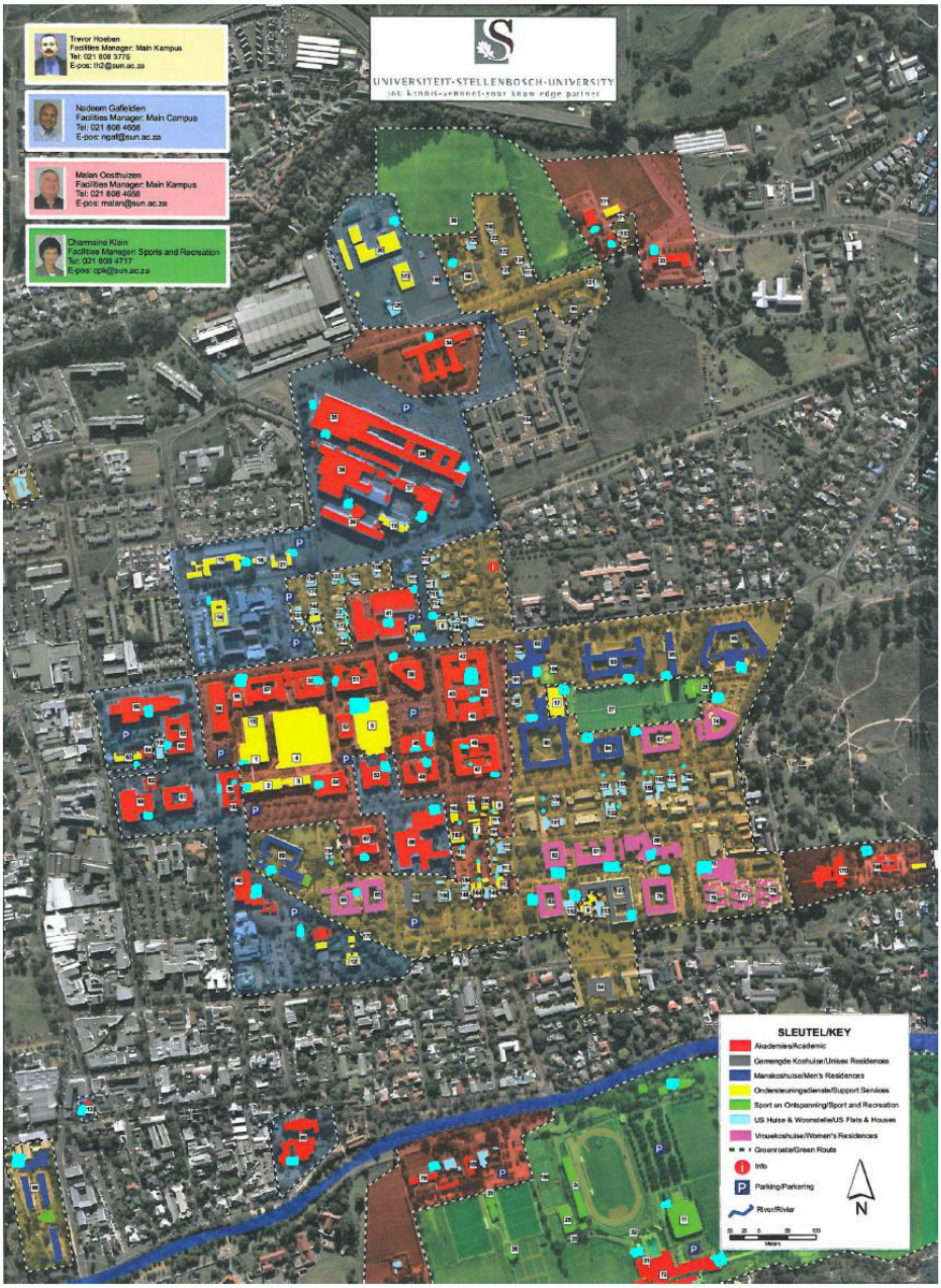
The recommendations listed above could provide interesting applications for sustainable decision making and assessment. Sustainability implementation is still limited, however it has the potential to make a positive contribution to the way organisations are operated and managed.

Appendix A

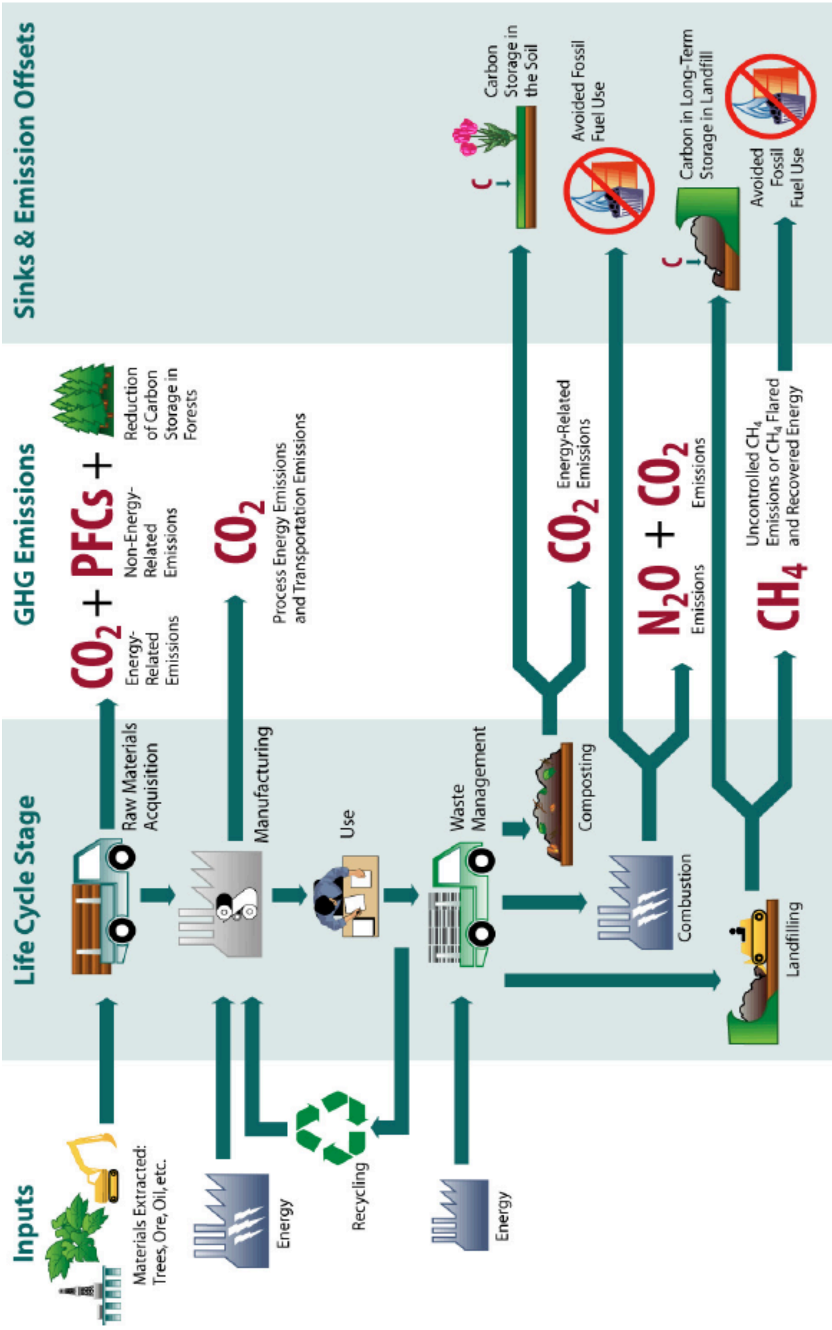
Framework Resources

The appendix is created in order to support the framework developed in Chapter 4. It consists of five items that are used by the LCA portion of the framework. The first diagram, Appendix A.1, is a map of the Stellenbosch University and is used in the life cycle inventory stage. The second diagram, Appendix A.2, represents the WARM tool which is used to calculate the *Carbon Footrpint*. The third item, Appendix A.3 used in the calculation of the value of different waste groups that were assessed. The fourth item, Appendix A.4, is a copy of the social acceptance survey, used to gauge the acceptance of a particular waste policy option from stakeholders. Lastly, the inteviews with relevant stakeholders and industry professionals in order to establish the basic operations and impact criteria, is represented in Appendix A.5.

A.1 Map - Main Campus



A.2 Waste Reduction Model (WARM)



A.3 Financial Value of Waste Types

Table A.1: Recycled material in Rands per ton

Type	Material	Price Range	Average (R/kg)	Comments
Glass	General Mixed	30c	R0.68	Consol Glass Stellenbosch
Plastic	PET	70 c	R R3.50	Two quotes
	PP	70c	R2.80	Plastic Recyclers Association
	PE-LD	70c	R2.50	Proplas (Pty)
	PE-HD	70c	R2.50	in Paarl
Metal	Metal Cans	3c	R0.50	-
	Foil	4c	R 0.34	
Paper	Office Paper	10c	R 1.00	Sappi Ltd.
	Mixed Paper	10c	R0.40	and
	Cardboard K4	10c	R 0.60	Mondi Ltd.
	Magazines	10c	R 0.10	were the
	Newspaper	10c	R 0.35	two sources
Compost	Organic Compost	R1.00	R10.00	Figures obtained from stellenbosch municipality

A.4 Waste Policy Acceptability

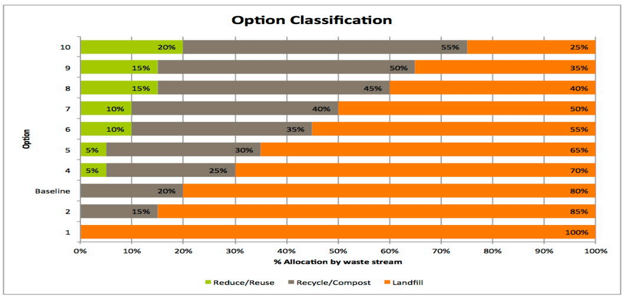
Waste Policy Acceptability

1. What is your Occupation?

☐ Undergraduate Student
☐ Post-graduate Student
☐ Lecturer
☐ Service Staff

2. What is your gender?

☐ Female
☐ Male



The above chart represents different waste management options that the University of Stellenbosch can deploy. Option 1, means that 100% of all the waste which the University produces is taken to the landfill. It then progresses to option 5, as shown above indicates a 5% less waste has been produced, 30% of all further waste is recycled and the 65% of waste is then taken to a landfill. Option 10, shows that 20% of waste has been reduced, 55% of all waste is then recycled/composted and only 25% of waste goes to landfill.

Reduce/Reuse - refers to the amount of waste that does not enter the waste system. That means that waste that is never created.

Recycle/composting - is that waste which is created, is diverted to be recycled or composted (in the case of food). The waste does therefor not end up on a landfill.

Landfill - Means that all waste that is generated will go of the Stellenbosch landfill.

3. For the options below, rank the social acceptability of each one. (1 - completely unacceptable, 5 - acceptable and 10 - Strongly acceptable)

	1	2	3	4	5	6	7	8	9	10
Option 1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Option 2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Option 3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Option 4	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Option 5	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Option 6	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Option 7	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Option 8	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Option 9	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Option 10	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

A.5 Interviews

Interview 1	
Name:	Prof. Harro von Blottnitz
Occupation:	Senior Lecturer of Chemical Engineering
Company:	The University of Cape Town (UCT)
Date:	28 June 2012
Time:	09:00
Place:	Faculty of Chemical Engineering at UCT
Topic:	Life Cycle Assessments

Interview 2	
Name:	John de Wet
Occupation:	Senior Technical Manager Stellenbosch University Facilities Management
Company:	Stellenbosch University
Date:	21 May 2012
Time:	11:00
Place:	Stellenbosch Municipal Offices
Topic:	

Interview 3	
Name:	Meg Pittaway
Occupation:	Grounds Manager Stellenbosch University Facilities Management
Company:	Stellenbosch University
Date:	18 January 2012
Time:	10:00
Place:	Stellenbosch University Facility Management Offices
Topic:	Initial Exploratory Interview

Interview 4	
Name:	John de Wet
Occupation:	Senior Technical Manager Stellenbosch University Facilities Management
Company:	Stellenbosch University
Date:	14 June 2012
Time:	11:00
Place:	Stellenbosch University Facility Management Offices
Topic:	Food Processing and Bokashi

Interview 5	
Name:	Meg Pittaway
Occupation:	Grounds Manager Stellenbosch University Facilities Management
Company:	Stellenbosch University
Date:	23 April 2012
Time:	14:00
Place:	Stellenbosch University Facility Management Offices
Topic:	Waste System and Data G3athering

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