# Economic and Environmental Impact Assessment of Construction and Demolition Waste Recycling and Reuse using LCA and MCDA Management Tools

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**A thesis submitted in partial fulfilment of the requirements of London South Bank University for the degree of Doctor of Philosophy**

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**May, 2016**

## Declaration

The author declares that to the best of his knowledge the work the work presented in this thesis is original and has not been or submitted to any university or learning institute for the award of higher degree.

Signature: ……………………………………….

Abioye Oyenuga

Date: ………………………………………………...

Dedicated to…

My Parents and Siblings

For always being there to guide me throughout my childhood and adult years, for encouraging, praising and loving me. I grew strong with your support, dependable and genuine love. Thank you all for your priceless affection

And to my sister Lade

For making me smile and laugh in times of frustration.

And finally to Lyfe

An expendable champion…you bring so much joy

# ABSTRACT

Reuse and recycling of waste from construction and demolition (C&D) is problematic because the markets for secondary materials have not yet been fully integrated. Decisions regarding the reuse and recycling of building waste materials, however, are beneficial economically to the construction industry, in addition to having environmental and social responsibility outcomes. The aim of this thesis is to evaluate the economic and environmental benefits of recycling and reuse of C&D waste. It explores how impact categories such as economic and environmental impact can be used to develop a decision-support framework for recycling and reusing building waste. Two case studies of real-life Demolition and New Build projects are selected to demonstrate how waste inventory data can be collected and adopted to support the decision-making process.

A thorough review of the available literature revealed a holistic view of C&D waste management and its related economic and environmental impacts. The literature review helped establish a direction for what is needed to develop a decision-support framework. Two management tools (LCA and MCDA) were identified as possible tools needed to complete the decision-support framework. Life Cycle Analysis (LCA) and Analytic Hierarchical Process (AHP) (an aspect of MCDA) were adopted to construct the framework, which was to be applied to the case study's waste management system. The combination of these two management tools enables the full development of a framework that can measure both the economic and environmental impact of the current waste management system, as well as act as a tool for supporting decisions regarding different policy alternatives.

Thus, the framework was applied to the Demolition and New Build case studies, and later validated for consistency. The framework delivered a set of positive results that could be useful for those making decisions on policy alternatives. Both the decision making process and waste management policy were selected and facilitated by the new framework. Decision makers' preferences on policy alternatives were ranked as final outcomes, and favoured reducing, recycling and reusing opportunities in C&D waste management. The result depicts an approach that, compared to current waste management practices, demonstrates a strong acceptability in terms of the environment and cost-effectiveness. Thus, the key findings discussed here provide an interesting foundation for future research, which will focus more on other impacts, such as the social and policy impacts of recycling and reusing C&D waste.

# ACKNOWLEDGMENTS

*Gratitude is a great virtue.*

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

1. My first supervisor, Vice President (Development) Executive Professor Rao Bhamidimarri and my second supervisor, Director Dr Shamil Naoum Director of Studies – Postgraduate Research Reader – Property, Surveying and Construction for their unfailing and invaluable guidance, motivation and assistance during the course of carrying out and completing the research.
2. To the "faculty" (Engineering, Science and Built Environment: now School of Built Environment and Architecture) for granting me a research scholarship.
3. Dr. Andy Lim, Dr. Ezekiel Samson, Tina Georgias, Patrick Ofili, Peter Opashi, Vighnesh Daas, Waheed Oseni, Oluwagbenga Samuel Tade for their guidance and support.
4. Global Construction Company (GCC) site management team for research material and insight.
5. My parents, friends, and co-workers at JPMC for their encouragement and understanding during this period.
6. To the many others who provided references, ideas, information, advice or encouragement – thank you.

The Author

May, 2016

# GLOSSARY OF TERMS AND ABBREVIATIONS

| Terms or Abbreviation | Definition |
|---|---|
| **AHP** | Analytic Hierarchy Process |
| **C&D** | Construction and Demolition |
| **CR&D** | Construction, Remodelling and Demolition |
| **CPA** | Construction Product Association |
| **$C0_2$** | Carbon dioxide |
| **$C0_2$ e** | Carbon dioxide emission |
| **CI** | Confidence Interval |
| **CR** | Consistency Ratio |
| **CRWP** | Construction Resources and Waste Platform |
| **Defra** | Department of Environmental, Food, and Rural Area |
| **DoE** | Department of the Environment |
| **EPA** | Environmental Protection Agency |
| **GCC** | Global Construction Company |
| **Kg** | Kilograms |
| **LCA** | Life Cycle Assessment |
| **LCI** | Life Cycle Inventory |
| **LCM** | Life Cycle Map |
| **MC** | Material Cost |
| **MCDA** | Multi-Criteria Decision Analysis |
| **MSW** | Municipal Solid Waste |

| | |
|---|---|
| **$M^2$** | Metres squared |
| **NSCC** | National Specialist Contractors Council |
| **NPV** | Net Present Value |
| **PC** | Processed Cost |
| **P** | Profit |
| **RC** | Recycling Cost |
| **RI** | Random Index |
| **RCA** | Recycled Concrete Aggregate |
| **3R's** | Reduce, Reuse, and Recycle |
| **SWMP** | Site Waste Management Plan |
| **TC** | Transportation Cost |
| **US** | United States |
| **UK** | United Kingdom |
| **UNEP** | United Nations Environment Program |
| **WMH** | Waste Management Hierarchy |
| **WMS** | Waste Management System |
| **WRAP** | Waste and Resources Action Programme |

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# CHAPTER 1: Introduction

## Chapter Aim:

The aim of the chapter is to introduce the underlying concepts that will be adopted throughout the thesis. A well-defined problem statement and hypothesis is then outlined. Thereafter, the research design is established that will attempt to address the overall research objectives.

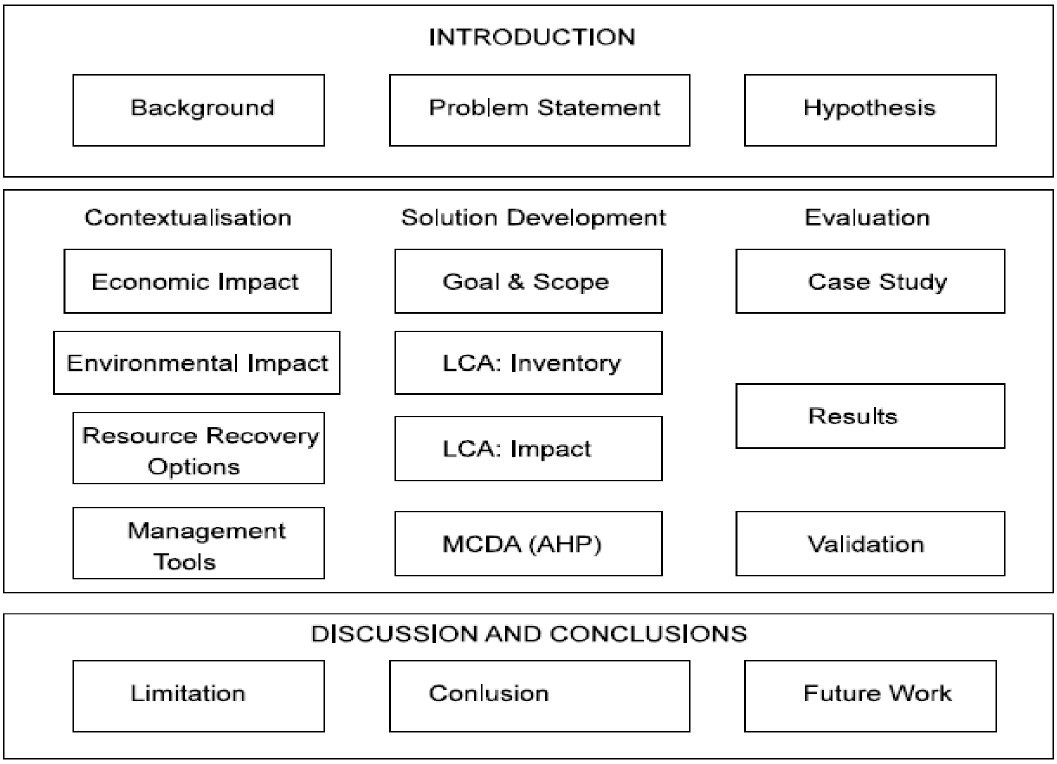


Figure 1: Research Outline (Source: Designed by Author, 2015)

## Chapter Objectives

- **Exploration** of research sphere.
- **Definition** of research problem and hypothesis.
- **Design** of research work.
- **Designation** of thesis structure.

## 1.1 Background

Waste has presented governments, business communities and demolition contractors who generate waste, as well as researchers in many countries, with challenges, raising issues concerning management of natural resources, environmental protection, health and safety, and profitability. Over the past decades, construction and demolition (C&D) waste issues have received increasing attention from both practitioners and researchers around the world. Construction waste seems to have caused serious environmental problems in many large cities around the world over the past decades (Chen and Wong, 2002). It is generally known, however, that huge amounts of infrastructure and building work have been undertaken over the years, as demolition of existing structures became integral to these developments.

A few research studies argue that the construction sector has a great impact through extraction of aggregate, production of cement, and proliferation of landfill sites and dust harmful to public health and the environment (Duran, et al., 2006; Bravo, 2010; Zhao, et al., 2010; Tam, 2011). Interestingly, waste is a major challenge to most societies and is generally defined as any material by-product of human and industrial activity that has no residual value (Weber et al., 2009; Yuan and Shen, 2011). To understand the environmental implications of building waste fully, and to achieve sustainability in many building projects, it is important to understand the size of the construction and demolition waste stream in order to mitigate the current problem.

In 2010, construction waste figures show that, in outright terms, the amount of waste going to landfill has increased by 2.58 million tonnes to 12.27 million tonnes compared to 2009 (an increase of 27%). Hobbs (2011) further argued that the reason for the significant increase in the amount of waste diverted to landfill is that more soil and stones were being landfilled in 2010. According to the Construction Product Association (CPA, 2012) waste figures for the construction industry show a significant improvement in reducing the amount of C&D waste being diverted to landfill.

Significantly, the construction industry waste figures in 2012 reduced to about 1.87 million tonnes as compared to 2008, due to the UK embarking on a long-term commitment to end the disposal of building waste in landfill as far as practicable, and to maintaining a *'zero C&D waste'* by 2020. Hobbs' report, entitled 'CD&E waste: Halving Construction, Demolition and Excavation Waste to Landfill in England by 2012 compared to 2008', indicated plans to halve the amount of construction waste being diverted to landfill in 2012 (Hobbs, 2012).

Recycling and reuse of construction materials is the answer to meeting the target of halving construction waste being diverted to landfill. The recycling and reuse initiative is intended to establish an economically viable framework for managing building waste by, avoiding demolition and reconstruction costs by reuse *in situ*, reducing costs of sending materials to landfill sites, and getting planning permission, especially in conservation areas (Berge, 2001; Addis and Schouten, 2004; Addis, 2006). The rate of recycling of C&D waste in Europe varies significantly between countries. Some countries have recycling rates of less than 10%, while others have recycling rates much greater than 10%, reaching over 90% depending on waste practices and availability of local incentives (Dosal et al., 2013).

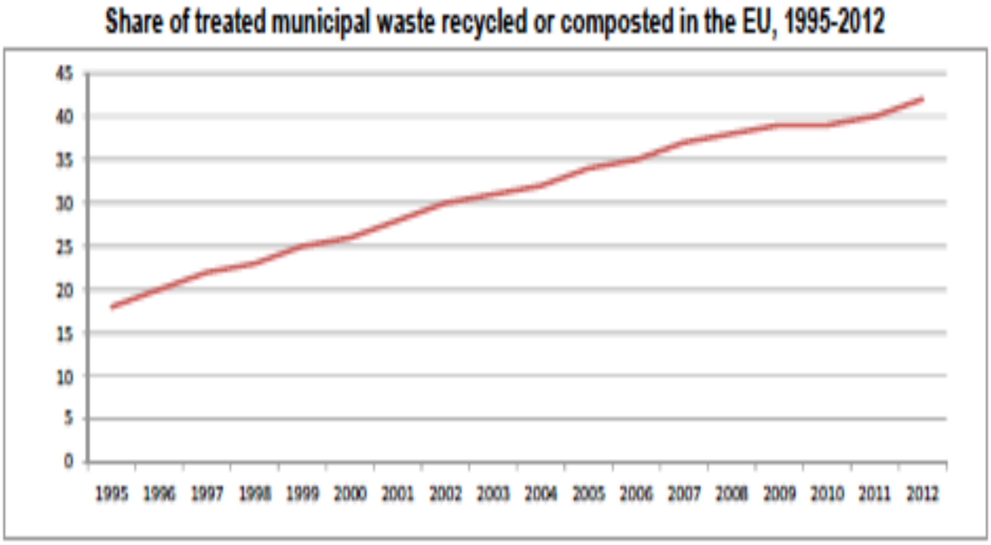


**Figure 2: Municipal waste recycled or composed in the EU, 1995-2012 (Source: Eurostat, 2014: Environment in the EU28)**

In 2012, more than 50% of municipal waste was recycled or composted in EU member states such as Germany, Austria, and Belgium (Eurostat, 2014). Relatively low rates were found: between 39% and 60% were found in EU member states such as France (39%), Luxemburg (47%), and Ireland (45%), according to EC data. This source also reports that countries such as the United Kingdom, Ireland, Demark, Germany, Estonia, and the Netherlands have already fulfilled the European Directive target (EC DG ENV, 2012). The recovery rate from non-hazardous C&D waste in the UK in 2012 was 86.5%. There is a EU target for the UK to recover least 70% of C&D waste by 2020 (Defra, 2015). Figure 2 shows the extent of treated municipal waste recycled or composed between 1995 and 2012. It is obvious that the rate of waste recycling has continued to increase in recent years. With this in mind, it should be understood that the separation techniques for many building waste materials often require advanced technology solutions as well as available legislative control with consideration for implementing the three 'R's (reduce, reuse, recycle) waste management concepts (Aadal et al., 2013).

Thinking about waste management concepts from a limited perspective often results in growing interest in some economic concerns. This is because there is a huge monetary value in diverting waste into landfills and tackling the effects of waste disposal on the environment. A recent study by Marzouk and Azab (2014) identifies the scarring effects of waste disposal in landfill on the environmental, which include: diminishing landfill space, depleted building materials, increased contamination from landfills leading to serious negative health effects, damage to the environment, and increased energy consumption for transportation and the production of new materials.

## 1.2 Research Sphere

The analysis of the economic and environmental impact of the recycling and reuse of C&D waste, waste management and decision-making are four elements of the research sphere addressed in this thesis. Therefore, the practical solutions to the problem statement for this thesis lie at the intersection of all four elements, as represented in Figure 3.

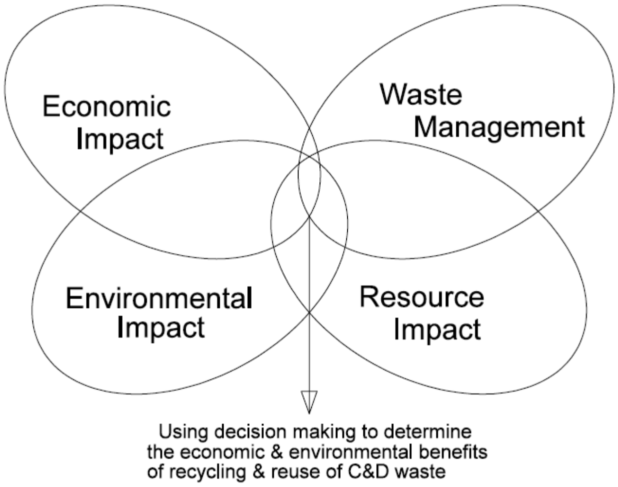


Figure 3: Research Sphere (Source: Designed by Author, 2015)

### 1.2.1 Economic Impact

The term economic impact is of growing interest across all disciplines. This often relates to the effect that an event, policy change, or market trend will have on economic factors such as interest rates, consumer confidence, stock market activity, or lack of jobs. For the purpose of this thesis, economic impact requires the synthesis of the economic objectives in relation to waste management. The research estimates the impact of recycling and reuse of C&D waste and sought to develop a decision-support model to gauge the economic benefits of the process.

### 1.2.2 Environmental Impact

The term environmental impact has gained recognition, particularly in term of global warming challenges and the pursuit of green development. Possible adverse effects caused by a development, industrial, or infrastructural projects or by the release of a substances into the environment, are of increasing concern. For the purpose of this thesis, environmental impact is considered in relation to environmental objectives in related to waste management. The research measures the estimated energy, water, greenhouse gas and landfill savings of recycling and reuse of C&D waste.

### 1.2.3 Waste Management

Waste management in this research refers to the management of Municipal Solid Waste (MSW) and not other liquid, gaseous, and radioactive waste materials. Thus, solid waste relates to all materials, products, and items discarded by society when no longer needed or known to be unwanted. For the purpose of the research it refers specifically to C&D waste produced by the UK construction industry.

### 1.2.4 Decision Making

Decision-making is the primary function of most management to solve most problems. It directs and controls the process allowing a system to function efficiently. Decision-making ensures clear context, definition, goal, boundary and information to be considered. It can be regarded as a problem-solving activity concluded by a solution deemed to be satisfactory. A major part of decision-making involved the analysis of a finite set of alternatives described in terms of evaluative criteria. For the purpose of this thesis, decision-making requires multiple objectives and criteria that have been considered for a better outcome.

## 1.3 Statement of the Problem

In line with the growing concern around the world about C&D waste management, an attempt has been made to quantify the amount of C&D waste in the UK. There are key challenges, however, in establishing the economic and environmental benefits of managing C&D waste. Today, C&D waste accounts for 30-35% of total municipal solid waste streams internationally, and most C&D waste is delivered, without undergoing treatment, to suburban or rural areas of disposal by means of open storage or landfill (Moussiopoulous et al., 2010). C&D waste has increasingly created serious social, economic, and environmental problems. There is no coherent framework for the utilisation of this waste, which is disposed of both appropriately and inappropriately. This harms the environment, contributes to the increase of energy consumption, and depletes finite landfill resources (Marzouk and Azab, 2014).

C&D waste includes a wide range of materials depending on the source of the waste. These include excavation materials (i.e. earth, sand, soil, gravel, rocks etc.), road building and maintenance materials (e.g. sand, gravel, and metals), demolition materials (i.e. debris consisting of earth, concrete, gravel, gypsum, porcelain, lime–cast and bricks) and other worksite waste materials (i.e. cardboard/paper, glass, plastics, wood, and metal). It is known that C&D waste not only incurs high transportation costs but also occupies valuable land. Statistically, construction, demolition, renovation, and refurbishment works account for around 100 million tonnes of waste in the UK each year (Osmani, et al., 2012). In many countries, C&D waste is commonly disposed of at designated landfill sites, with only small amounts being recycled.

The depletion of natural resources and the difficulty of locating landfills suggest that there should be consideration of alternative ways of managing C&D waste (McGrath, 2001; Zhao, et al., 2010; Srour, et al., 2012). A few studies have proposed strategies including reducing the amount of waste produced and diverting it from landfills by implementing reusing and recycling initiatives (Peng et al., 2010; Zhao, et al., 2010; Hwang and Yeo, 2011). Osmani, et al., (2012) identify some challenges with recycling operations in many construction sites, such as excessive building material waste, ineffective management on the construction site, scarcity of data available on waste management strategies, and lack of administrative capacity. These have become common in recent times.

Problems with government intervention in waste management practices are yet to be addressed, as a few building developers, recyclers, and contractors consistently rely on the

Site Management Plan, which places more emphasis on maximising profit than on controlling the generation of C&D waste and its environmental impact. A few studies have recently been dedicated to evaluating the environmental impact of C&D waste treatment, specifically using the Life Cycle Assessment (Banar, et al., 2008; Ortiz, et al., 2010; Milani, et al., 2011; Coelho and deBrito, 2013). One important aspect of waste management planning is the identification of areas in which specific measures should be taken in order to reduce the environmental impacts of waste management.

The performance of management alternatives in the decision-making process is still limited, and consideration of the environmental aspects in addition to the evaluation of technical and economic aspects are still to be fully integrated. The waste diverted to landfill is often the final stage of all materials, which cannot be reused or recycled. One of the most pressing problems facing municipalities is how to balance the overall energy and $CO_2$. It is quite intriguing that, even in the worst conditions, installing and operating C&D recycling operations is still environmentally justified, although the economic impact of recycling operations remains a major challenge. The impact of recycling operations varies significantly, as the extent of operations for various locations remains a key factor to be considered. The issue of location-specific for managing C&D waste has limited the outcome of recycling and reuse activities. The question is whether environmental and economic benefits can be achieved from a C&D waste recycling operation. If the answer is yes, we need to consider how this be achieved using an appropriate decision-support framework.

Initial research has indicated that both Life Cycle Assessment (LCA) and Multi-Criteria Decision Analysis (MCDA) are two key management tools that can be used to improve the sustainable management of C&D wastes (Karmperis, et al., 2013). The motivation for this research is based on different arguments. C&D waste is greatly affected by economic and environmental impact, as local contractors and recyclers are paying less attention to '*waste as a resource*' throughout the construction lifecycle. Available tools are yet to provide a realistic support for decisions regarding recycling and material reuse. The research described in the thesis specifically leverages contributions from construction waste generation research to develop a framework that can be used by construction researchers and C&D waste users to evaluate and improve C&D waste recovery in a quick, cheap and resourceful way in preparation for expensive, but essential, sustainable waste management studies.

## 1.4 Research Goal and Questions

The literature concerning the management of C&D waste through recycling and reuse of construction and demolition waste and its economic impacts (Weber et al., 2009; Zhao, et al., 2010; Srour, et al., 2012), has not considered environmental and economic perspectives in an integrated way. This current research seeks to close this gap by empirically gauging the economic and environmental impact of the recycling and reuse of C&D waste, paying special attention to identifying the types of construction materials that can be reused and recycled. The aim of the thesis is to evaluate the economic and environmental benefits of recycling and reuse of C&D waste and to develop a decision-support framework for the reuse of C&D waste.

In order to achieve the research aim, the following objectives are set: to appraise approaches in evaluating the economic and environmental benefits, to identify the opportunities for recycling and reuse of C&D waste; to investigate the legislative and other barriers for efficient recycling and reuse of C&D waste; to develop an economic analysis of the recycling and reuse of C&D waste, including the economic value of the environmental benefits; to examine decision-making regarding the reuse of C&D waste before arriving at a decision-support framework.

### 1.4.1 The Core Aim of this Ph.D. Thesis

The core aim of this Ph.D. research work is:

*"To evaluate the economic and environmental benefits of recycling and reuse of C&D waste and to develop a decision-support framework for reuse of C&D waste"*

In order to achieve this aim, this thesis provides answers to the following research questions:

**Main question:** Can Life-Cycle Assessment (LCA) and Multi-Criteria Decision Analysis (MCDA) be adopted to better evaluate the economic and environmental benefits of recycling and reuse of C&D waste?

The question leads to the null hypothesis:

> $H_0$: ***A decision-support model based on LCA and MCDA is not able to improve evaluation of economic and environmental benefits of recycling and reuse of C&D waste.***

Specific research questions are:

**Research question 1**

*“What is the scale of C&D waste problem and what are the economic and environmental impacts of the C&D waste?”*

The answer to the first question will identify key issues with C&D waste and provide basic information on the economic and environment impacts of C&D waste. The environmental problems associated with landfills are immense and apart from the aesthetic degradation of the environment and the destruction of the natural topography and vegetation, landfills can be full of hazardous substances, which contaminate the soil, the groundwater, and the environment. However, the underlying question seeks to investigate the economic and environmental benefits of reuse and recycling C&D waste as a means to avoid landfill.

**Research question 2**

What are the logistic and legislative barriers for reuse of C&D waste?

The answer to the second research question will systematically identify logistic and legislative barriers for reuse of C&D waste. Special attention is placed on key issues with government policy on C&D waste management as well as management strategies. This is to uncover underlying issues with economic and environmental viability of managing C&D waste.

**Research question 3**

What economic and environmental value can be gained through recycling and reusing of C&D waste?

The answer to this question will show the economic and environmental viability of reusing and recycling of C&D waste. From this investigation, both carbon footprint measurement and cost savings will be evaluated.

**Research question 4**

What decision-support framework will enable the assessment of effective and efficient reuse of C&D waste? In response to this question, an attempt is made to construct a decision-support framework, appropriate for the assessment of an effective and efficient recycling and reuse of C&D waste.

## 1.5 Outline Methodology

This section describes the research methods used to achieve the objectives of this study. The research reflects how research is to be carried out.

### 1.5.1 Research design

Mouton (2001) refers to three unique classifications of research design: quantitative, qualitative, and mixed methods. Research studies can seldom be classified as one or the other. Therefore, they can be referred to as being more quantitatively or qualitatively oriented. The design will attempt to address the proposed research questions and objectives. The methodology is designed to give a logical and insightful answer to the research questions posed in section 1.4.1. Figure 4 below describes the methodology followed in this thesis. In the introduction chapter the problem statement is described and the hypothesis is framed.

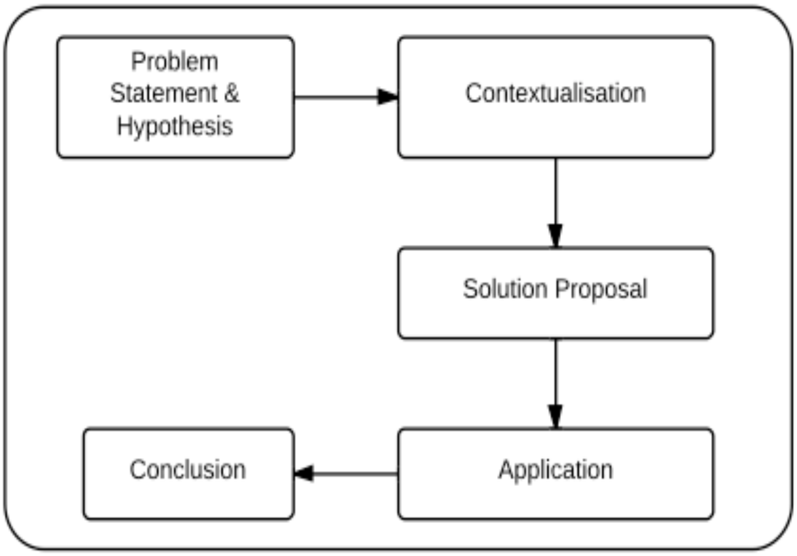


Figure 4: Research Design (Source: Designed by Author, 2015)

A review of available literature was undertaken in order to contextualise the problem and to analyse approaches to the development of solutions. A proposed solution is then developed and applied to two case studies. The outcomes of the case studies are analysed in relation to the parameters set out in the proposed solution. Thus, the research objectives will be addressed according to the structure below:

Table 1: Research Objectives (Source: Designed by Author, 2015)

| | |
|---|---|
| | **Chapter 2** |
| **Contextualisation** | 1. Contextualise C&D waste stream, waste management and its applications<br>2. Identify the opportunities for recycling and reuse of C&D waste<br>3 Investigate the legislative control and other barriers for efficient recycling and reuse of building waste |
| | **Chapter 3** |
| **Analysis** | 4. Investigate relevant waste management tools in detail<br>5. Assess effectiveness of management tools for economic and environmental measures<br>6. Appraise approaches in evaluating the economic and environmental benefits of recycling and reuse of building waste |
| | **Chapter 4** |
| **Solution Development** | 7. Examine attributes to decision making in the recycling and reuse of building waste<br>8. Develop a decision support framework |
| | **Chapter 5** |
| **Evaluation** | 9. Application of framework to case study.<br>10. Access the framework outputs<br>11. Validate outcomes |

The first objective, contextualisation, creates a theoretical foundation and thereby develops a backbone for the entire study. Chapter 2 includes the statement of knowledge that provides a thorough understanding of the economic and environment benefits of the recycling and reuse of C&D waste. Chapter 3 explores the available management tools that can be used to develop a decision-support framework.

A proposed solution is discussed. The solution will further draw upon the key findings of the literature review. This further addresses the goals of the economic and environmental benefits of reuse and recycling as well as the decision-making framework for the entire process, using LCA and MCDA.  At the application phase, the proposed solution involves three objectives: the application of the framework to two selected case studies (medium and small-scale projects); focusing on assessing the outcome of the framework on the case study; validating the outcome of the framework.

In order to understand the outcome of the research better, two methodologies (LCA and MCDA) are considered to develop a decision-support model. These methodologies are selected to guide data collection, calculations, evaluation of decision-support models, and analysis. To understand the economic and environmental benefits of managing C&D waste, a decision-support model is proposed. Decision-support models can help practitioners to select sustainable and cost-effective methods for the recycling and reuse of C&D waste (Quariguasi, 2008; Banar, et al., 2011).

In order to assess C&D waste management strategies, and to quantify the environmental and economic impacts of C&D waste, Life Cycle Assessment methodology (Banar, et al., 2008) is used. MCDA is considered in order to handle more than one data set and to help decision-makers to address the problems of waste generated on construction sites (Roussat, et al., 2009). A multi-disciplinary approach is important in dealing with the complexity. This research engaged a range of professionals and practitioners to gain information and analysis.

## 1.6 Scope and Positioning

The scope of the thesis is in fourfold. The first is a better understanding of management processes of construction and demolition (C&D) waste: what are the processes behind effective management; what monitoring and control systems are in place; what are the driving forces behind these processes; are there any lock-ins in the process? Second, what parameters are available for constructing a decision-making framework for the reuse and recycling of C&D waste? If known, how can these attributes be identified and implemented? Third, what C&D waste can be reused, recycled, and reduced, what are the economic and environmental impacts of C&D waste, and how can these be managed throughout the lifecycle of the construction process? Thus, this research aims to grasp the underlying principle behind the reuse and recycling of C&D waste from a research viewpoint, as well to contribute to existing knowledge on the economic and environment benefits of C&D waste.

## 1.7 Structure of this Thesis

The structure of the thesis addresses the need for the research goals and corresponds to the stated research design.

**Chapter 1: Introduction**

Chapter 1 introduces the research problem, objectives of this research, methodologies, and anticipated outcomes

**Chapter 2: State of Knowledge**

Chapter 2 presents the state of knowledge, discussing: waste and its definitions, C&D waste composition, economic and environmental implications, sorting and management consideration, waste management hierarchy, roles of waste management, waste management legislation and policy implication.

**Chapter 3: A Review of Available Management Tools**

Building on the information in Chapter 2, Chapter 3 presents the theoretical foundation of the thesis, discussing: waste management tools in relation to environment and economic measures.

**Chapter 4: Building a Decision-Support Framework**

Adopting the management tools reviewed in Chapter 3, the purpose of Chapter 4 is to develop a framework to enable assessment of economic and environmental benefits and to consider factors in decision making for recycling and reuse process for C&D waste.

**Chapter 5: Case Study**

Chapter 5 applies the framework developed in a real-life case study to two medium and small-scale Demolition and New Build projects in North London, United Kingdom. The outcome of the two case studies are examined and discussed. The framework and research outcomes are then validated.

**Chapter 6: Discussion and Conclusions**

Chapter 6 evaluates the research that was conducted. Central arguments and key findings are discussed. The limitations of the research and of the proposed decision-support framework are discussed. The overall conclusions presented.

**Chapter 7: Recommendation for Future Work**

Chapter 7 recommends for future work.

# CHAPTER 2: State of Knowledge

## Chapter Aim:

The purpose of the chapter is to capture the available knowledge related to C&D waste generation, to conceptualise underlying principles of waste management and to address the issue of economic and environmental impact in relation to recycling and reuse of C&D waste. The chapter further focuses on the status of C&D waste management, overview of waste management legislation and policy and the underlying issues with legislation. This led to an extension of the literature into an exploration of available management tools identified in chapter 3.

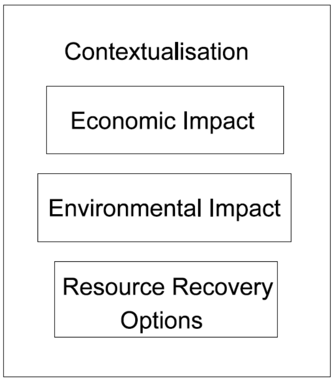


Figure 5: Contextualisation I (Source: Designed by Author, 2015)

## Chapter Objectives

- **Contextualise** C&D waste stream and components
- **Identify** the opportunities for recycling and reuse of C&D waste
- **Investigate** the legislative control and other barriers for efficient recycling and reuse of C&D waste.

## 2.1 Waste

### 2.1.1 Waste definitions

Waste is considered to be an unwanted good that is no longer useful or desirable. Waste may emanate from human activities as well as natural processes. Examples include, Municipal Solid Waste (MSW), agricultural and animal waste industrial residues, extraction and mining waste, construction and demolition waste, food waste etc. Other definitions refer waste to as of a material, substance, or by-product discarded as no longer useful or required after the completion of a process. European Union defines waste under the Waste Framework Directive as an object the holder discards, intends to discard or is required to discard (European Council, 1991). According to Sperpell and Alarcon (1998) waste is defined as any material by-product of human and industrial activity that has no resident value.

"Waste" is often subjective in nature due to individual perception and lack of understanding of the value. For example, to divert scrap metals to a landfill is to inaccurately classify them as waste, since they are recyclable. According to the United Nations Environment Program (Basel Convention) waste are substance or objects, which are disposed of or are intended to be, disposed of or are required to be disposed of by the provisions of national law (UN Environment Program, 2005). Drawing closer to the meaning of waste early definition by OECD refer waste as materials other than radioactive materials intended for disposal (OECD, 2003).

### 2.1.2 The Notion of Waste

The notion of waste has two perspectives. One, an object or substance becomes 'waste' when it its primary functions are reduced for the end-user, however people's waste output is often related to their input. Two, the notion of waste is related to the technological state of the art and to its developmental location. Following these two perspectives, waste can be referred to as dynamic concept in nature. According to the European Chemical Industry Council (CEFIC, 1995) the nature of a material is not enough to be considered as 'waste', however, this can be based on the actions or intentions of the holder. Construction waste producers are quite cautious of the amount of waste produced and generated through construction works.

Estimate of waste produced during construction works are quantified during design and construction phase, however specific building materials produces more waste than others during application. The presence of waste is an indication of overconsumption and that materials are not being used efficiently. Dealing with waste takes extra effort and commitment. Most modern waste management strategies are focused at local government level and based on technology (reuse/recycling) and high-energy waste disposal methods such as incineration landfill.

### 2.1.3 Waste in Construction

Waste in the construction industry requires a strategic approach to reduce its overall waste generation for environmental and economic benefits. However, changing people's behaviour towards waste can make significant challenge. According to Teo and Looosemore (2001) waste can be perceived as an inevitable by-product of construction activity. The author further explained that many attitudes towards waste are often considered pragmatic rather than being negative. However, authors argued that the issue of ineffective management remain a concern in recent times. Waste behaviour can be perceived by the waste handlers' attitude towards material usage and understanding of its value.

The attitude to waste is reflected by people's willingness to change their attitudes and behaviour. Memon (2012) argues that people have failed to follow the waste management concepts in construction sites as attitudes and behaviour differ across different organisations. Construction waste consists of unwanted materials produced directly or incidentally by construction, both on and off sites. This includes building materials such as insulation, nails, metals, drywalls electrical wiring as well as waste originating from site preparation such as dredging materials, tree stumps, lead, steel, aluminium, plastics, asbestos and rubble.

The role of human behaviour in construction waste generation had been discussed in several studies (Lingard et al., 2000; Teo and Loosemore 2001, Dainty and Brooke, 2004). These studies have shown that there is shortcoming in the implementation of the waste minimisation initiatives within the UK construction industry. Many construction sites often produce significant volume of waste. The complexity of the industry has driven the need for an effective management system to help waste producers to reduce the amount of waste during demolition and construction works.

## 2.2 Construction and Demolition (C&D) Waste Stream

Construction and demolition (C&D) waste consist of debris generated during the construction, renovation, and demolition of buildings, roads, and bridges. Construction waste combines demolition waste containing bulky, heavy materials, which include concrete, drywall, bricks, wood, plastic, metals, glass, and salvaged building components such as windows, doors, metal frame, plumbing fixtures etc. Waste materials resulting from construction and demolition of buildings and infrastructure constitute a significant amount (10-15%) of the total municipal solid waste stream (Gavilan and Bernold, 1994; McGrath, 2001). C&D waste consists of common building materials such as bricks, plastics, paper/cardboard, garden/vegetation, wood/timber, carpets, other textiles, rubber, glass, plasterboard, metals, ceramic, rubble, clean soil, concrete and asphalts, insulation (Memon, 2012).

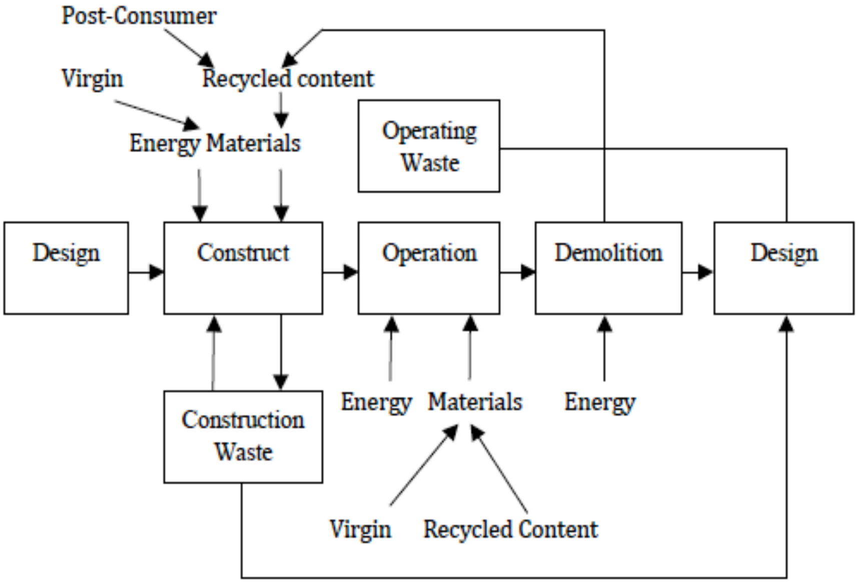


Figure 6: Building Material used and C&D waste generation in the life cycle of buildings (Cited in Duran et al., 1999)

In practice, the estimates from residential construction generate a high level of waste on new construction. However, a number of researches argue that waste stream varies according to construction type (Duran, et al.2006; Zhao et al., 2010). In 2009, BRE's estimate on construction demolition activity provides that 80% of demolition materials are inert materials (i.e. 59% concrete and 21% soil), 10% metals, 7% timber, and 1.4% plasterboard (CRWP, 2009). Also, this source argued that 88% of inert materials and full metals handled by demolition contractors are processed for recycling. It is reported that about 80% of this waste stream is being recycled and used (CRWP, 2009).

The C&D waste is not a homogeneous waste stream as there is a need to define the types of materials, which could be available in C&D waste. The most common materials are paper/cardboard, wood, rubber, glass, plastics, metal, drywall, soil, concrete, bricks, insulation etc. Lewis (2011) argued that waste stream varies according to construction type (residential, commercial, demolition etc.) such that residential projects generate the largest amount of waste.

### 2.2.1 Aggregates/Concrete/Rock-Pile

Aggregates play a major role in the construction industry, as they are the major component of roadways, bridges, airport runways, concrete buildings drainage systems, and other constructed facilities. Construction aggregate is considered as a broad category of coarse material used in construction, including sand, rock pile, gravel, crushed stone, slag, recycled concrete, and geosynthetic aggregates. Aggregates are generally known as a component of composite materials such as concrete and asphalt concrete, which serves as reinforcement to add strength to the overall composite material.

Concrete is considered to be 75% aggregate and the proportioning and properties are critical to performance of the finished product. Concrete is made up of cement, water, and aggregate, such as crushed stone, sand, or grit. Mixed with cement, crushed concrete can be used for projects that call for a cement-stabilized base. This recycled material is less expensive than crushed rock alternatives, and it helps preserve the environment by reducing the need to mine new materials. Traditional approach to end of concrete life cycle often result to waste materials considered for disposal.

Arguably, the costs associated with the increasing tipping fees and fading landfill space, many transportation agencies are embarking on innovative ideas to recycle concrete products. Moving towards sustainable approach to construction waste, Recycled Concrete Aggregate (RCA) is developed with higher strength than original virgin aggregates. RCA offers an alternative to wasting concrete elements that are no longer in use. The origin of the concrete from which RCA is developed includes the demolition of transportation structures such as existing concrete pavement and runways etc.

Interestingly, '*rock pile'* is another natural resource aggregate, which is considered bulk gravel. It is a natural, stone that is quarried all over the world. As natural product gravels are prone to variations in colour, size, and shape with less control on consistency of the product. It is found that no two loads of gravel are identical. Rock pile is locally owned and operated and has steadily grown from a small crushing entity to a full service bulk aggregate. Rock pile provides an extremely cost-effective alternative to natural aggregates and also provided the construction industry with economic and environmental benefits by recycling clean concrete rubble and asphalt into landscaping materials.

### 2.2.2 Excavated Soil/Sand

Construction of buildings and infrastructure require use of construction materials, earthwork, transportation and management of large volumes of materials such as aggregates and excavated soil and rock pile. Depending on local geological conditions and anthropogenic activities, excavated material can be rock, stones, gravel, sand, clay, organic material and materials from previous constructions or industrial activities. Various types of buildings are built by using soil as a construction material.

The quantities of excavated soil and sand can be considerably big and hauling and handling costs high. In infrastructure projects, on-site handling and hauling of excavated soil and rock and construction material from quarries, i.e. quarry material, can be up to 30% of the total project cost and generate significant amounts of $CO_2$ emissions (Kenley and Harfield, 2011). Soil is a fundamental and ultimately finite resource that fulfills a number of functions and services for society.

Soil is a vulnerable and essentially non-renewable resource. Topsoil which is the soil layer contain up to 5 tonnes of living organisms and because it can take more than 500 years to form a 2cm thickness. Soil fulfills a number of functions and services for society, which is central to social, economic and environmental sustainability (Defra, 2009). Some of the most significant impacts on soil properties occur as a result of activities associated with construction. Construction activity can have adverse impacts on soil in many ways by:

- Covering soil with impermeable materials, effectively sealing it and resulting in significant detrimental impacts on soils' physical, chemical and biological properties, including drainage characteristics;
- Over-compacting soil through the use of heavy machinery or the storage of construction materials;
- Reducing soil quality, for example by mixing topsoil with subsoil;
- Wasting soil by mixing it with construction waste or contaminated materials, which then have to be treated before reuse or even, disposed of at landfill as a last resort.

### 2.2.3 Ceiling Tiles/Insulation

Ceiling tiles/insulation is key part of construction and demolition debris. This include acoustic ceiling tile (i.e. panels made from variety of materials designed to reduce noise). Ceiling tiles are easier to recycle when generated in large volume. All brands of dry ceiling panels can be recycled. However hazardous materials such as asbestos-containing ceiling cannot be recycled in many recycling facilities. Insulation materials run from bulky fiber materials such as fiberglass, rock and slag wool, cellulose, and natural fibers to rigid foam boards to sleek foils. Bulky materials resist conductive and to a lesser degree convective heat flow in a building cavity.

Mineral wool insulation is typically a blend of rock wool and slag wool. Slag is what is left from coke and iron and is the predominant input material to most mineral wool insulation. If slag were not recycled, it would be sent to landfills, further aggravating the landfill problems. In the fiberglass insulation manufacturing industry, recycled scrap glass - mostly from bottles - is used as an input raw material. Scrap fiberglass can be used for more than just fiberglass board products. One commercially successful reuse is as an input ingredient for fiberglass acoustical ceiling tiles. The manufacture of mineral wool and fiberglass insulation is energy intensive. Any materials that can be recycled, without requiring the melting of input materials, can save large quantities of energy otherwise used to melt the materials.

### 2.2.4 Paper/Cardboard

Paper and cardboard products consist of mechanically processed cellulose fibers, such as wood or vegetable fibers. Products are readily available raw materials and relatively low production costs have made it the predominant material for lightweight, inexpensive applications. Hornbostel (1973: p.500) describes four categories of use of paper products in construction. These include building materials, containers and protective coverings, concrete, paper for administrative and supervisory purposes. However building materials that are paper or pulp-based typically fall into the following categories such as fibreboard, sheathing or roofing paper, insulation, felt, including asphalt or other mineral impregnates and gypsum board.

In the C&D sector cardboard is predominantly generated during the fit out stage of construction and at the point of occupation, especially in the residential construction sector. The construction industry is unsure of the potential quantities coming from the residential construction sector, and it was acknowledged that reprocessors were not actively chasing cardboard material from the C&D sector (Kralj and Markic, 2008). Most kinds of paper can be easily recycled, including leaflets, wallpaper, newspapers, and scrap papers. A key issue with the recovery of cardboard is that it is presented in mixed loads and may therefore be highly contaminated with abrasive materials that reduce the quality of cardboard and may damage processing equipment.

Large cardboard boxes from appliances and other corrugated containers can be reused on the construction site as storage containers or as intermediate waste containers. However, old cardboard is usually the most marketable material generated from construction site. Most recyclers do not accept wax coated cardboard or non-paper packaging materials as the cost of separation makes recycling economically unviable. Paper and cardboard can be recycled at paper mills or used for fuel pellets (Dolan et al., 1999). Paper and Cardboard is one of the simplest products to recycle and by maximising the reuse of this material one can all reduce the number of virgin trees being felled to create new products. Cardboard is a readily recyclable material with well-established local markets for processing and manufacturing.

### 2.2.5 Glass

Glass blowing was discovered in the 1st century in Europe, this revolutionized the glass making industry. The technique spread throughout the Roman Empire. Production of Clear glass, by introduction of manganese dioxide, saw glass being used for architectural purposes. In the 20th century modern architecture has been instrumental in mass production of concrete, glass and steel buildings. This helped accommodate housing needs of the burgeoning population. Glass remain an important aspect of construction which absorbs, refracts or transmits light which can take excellent polish, strong and brittle which excellent resistance to chemicals. Glass has become one of the most popular and complex building materials used today by offering virtually unlimited aesthetic options combined with outstanding performance.

Glass and steel construction have become the symbol of development in many countries, where people tend to see these buildings as symbols of affluence and luxury. Glass can be recycled into usable products which are separated by chemical composition, and then, depending on the end use and local processing capabilities, might also have to be separated into different colours (Zhao et al., 2010). Poutos et al., (2008) argued that glass recycling uses less energy than manufacturing glass from sand, lime and soda. Every metric ton

(1000kg) of waste glass recycled into new items saves 315 kg of $CO_2$ from being released into the atmosphere during the creation of new glass.

### 2.2.6 Plasterboard

Any diversion of plasterboard from landfill is mostly from construction activity, because the nature of mechanised demolition processes means this friable material is not readily separated from mixed loads. It is also considered a contaminant when presented in recovered C&D materials. For this reason it is one of the most challenging materials when seeking to improve the recovery of mixed C&D loads, even though plasterboard itself is highly recyclable. Most plasterboard recovery is from construction sites and is often achieved through arrangements between the construction company and the material supplier. Plasterboard manufacturers who supply construction sites will regularly support the recovery of clean product from the sites of companies who purchase their materials.

### 2.2.7 Ferrous and Non-Ferrous Metal

Metals are often categorized into ferrous and non-ferrous. Examples of ferrous metal include mild steel (which contain carbon content of 0.1 to 0.3% and Iron of 99,7-99.9%), carbon steel (carbon content of 0.6 to 1.4% and Iron content of 98.6 to 99.4%), stainless steel (made up of Iron, nickel and chromium), Cast Iron (carbon of 6% and Iron at 94 to 98%) and Wrought Iron (composed of almost 100% iron). On the other hand, non-ferrous metals include Aluminum, copper, brass, silver and lead.

Steel has the highest recycling rate in construction works across the world (Rankin 2011); more steel is recycled annually than aluminum, paper, glass, and plastic combined. All steel has recycled content, but the proportions of recycled content depend on the type of steel-making furnace used in the manufacturing process. There are two kinds of steel making furnaces: Basic Oxygen Furnaces (BOF) and Electric Arc Furnaces (EAF). The basic oxygen furnace uses 25-35% recycled steel to manufacture new steel. The electric arc furnace uses more than 80% recycled steel.

### 2.2.8 Wood

Wood waste generated during the construction process has value in the marketplace. But it is low enough value to justify collecting, processing, and transporting it to buyers. Wood waste arises from commercial, industrial and household sources, include construction, joinery, manufacturing and at a domestic level. Wood from C&D can be in many forms including trim ends, plywood scrap, solid lumber from cabinet and furniture construction, crates, spools, saw dust and wood chips. In addition, shavings, plywood, oriented strand board, particle board, fiberboard, laminated beams, shingles, I-joists, and treated wood such as decking, utility poles, marine pilings, and fence posts also form components of this waste stream. During remodeling, wood could be in the form of items that can be reused such as finished pieces of furniture, doors, or cabinets.

Wood waste arisings have increased substantially over the past three years due to reduced activity particularly within the construction, furniture and joinery sectors (WRAP, 2011). Wood recycling is commonly undertaken by small enterprises (Rankin, 2011). Demand for recovered wood from the panel board sector has declined as construction and furniture output have declined. However, total recycling and recovery of wood waste have increased due to the growth  (i.e. more that 0.4 million tonnes) in the use of recovered wood as animal/poultry bedding. Use of recovered wood in end markets increased by 35% between 2007 and 2010 as shown in Table 2 as wood recyclers sought to diversify from panel board sector recyclers and access higher value markets.

Table 2: End Market for Recovered Wood (Source: WRA, WPIF & HMRC, 2010)

| **Thousand Tonnes** | **2007** | **2008** | **2009** | **2010** | **07/08** | **08/09** | **09/10** |
|---|---|---|---|---|---|---|---|
| Panelboard | 1200 | 1126 | 1065 | 1119 | -6% | -5% | -5% |
| Animal/poultry bedding | 290 | 350 | 360 | 391 | 21% | 3% | 9% |
| Equine surfaces/bedding | 56 | 73 | 75 | 77 | 30% | 3% | 3% |
| Mulches, soil conditioners, composting | 75 | 95 | 98 | 95 | 27% | 3% | -3% |
| Pathways and coverings | 15 | 17 | 18 | 17 | 13 | 6 | -6% |
| Biomass/energy (UK) | 250 | 370 | 495 | 551 | 48% | 34% | 11% |
| **Total recycled/recovered in UK** | **1886** | **2031** | **2111** | **2250** | **8%** | **4%** | **7%** |
| Exports | 15 | 117 | 49 | 194 | 680% | -58% | 296% |
| **Total recycled/recovered** | **1901** | **2148** | **2160** | **2444** | **13%** | **1%** | **13%** |

### 2.2.9 Plastics

Plastic materials are commonly used for an enormous range of building materials. For almost every component of a building, with the exception of structural and mechanical systems, there is a synthetic, plastic counterpart. Plastics are used for wall finishes, flooring, textiles, roofing, plumbing, siding, furniture, and glazing. In general, there are different forms of plastics used on construction. These include coatings, flooring, extruded and moulded shapes, foam, fibres and textiles, laminates, film, sheets and panels. Plastic coatings such as liquefied plastics or cementitious coatings for masonry, concrete, wood, and roofing materials often includes epoxies, acrylics, polyesters, polyurethanes and vinyls.

Plastics are particularly suited for extruded and moulded shapes. This includes a wide variety of products including piping and fittings, gaskets, baseboard, shims, weather-stripping, electrical components and fixtures and furniture. These types of plastics include both thermoplastics such as acrylics fluorocarbons, polycarbons, polyamides, polyesters, polyethylene and polyvinyls. The most common use of plastics in flooring is vinyl resistant flooring. PVC piping, vinyl siding, and polystyrene packaging may be marketed if they are clean and generated in fairly large quantities. Plastic film is considered difficult to market because of the many different types of plastic used to make the various grades of plastic film. In terms of recycling opportunities, plastics can be easily recycled.

Plastics recovered from C& D waste can be separated, cleaned, and reformed into plastic lumber, highway barriers, and traffic cones. Plastic laminates are almost unrecyclable because they are a composite material with thermosetting resins. Building waste materials should be separated and stored where they will stay relatively clean. Plastics collected and separated by resin type have a higher market value and demand compared to mixed plastic. There are a few plastic building materials that can be separated by resin type for which potential market exists. PVC and vinyl siding are examples of C&D waste that have a high potential for separation and recycling.

## 2.3 Sorting and Management Consideration

Waste sorting follows construction site handling and processing of building materials mainly in connection with centralised waste management programmes, from its location at source to final end-use or disposal. Source separation is when C&D waste is sorted on the construction site by material type. This approach is beneficial in terms of recyclability; reducing cost of separation for the recycler and reducing risks of contamination. C&D waste is often mixed with all kinds of waste during demolition and construction works. This can be done in variety of ways, from basic manual sorting to mechanical means, the latter being more appropriate for larger volumes. Methods such as manual and mechanical sorting are used to sort recyclable concrete and bricks from other non-recyclable materials. Other approach to waste sorting is the use of crushers, which generally crush glass porcelain, granite, bricks, blocks, asphalt, and concrete.

Timber and other building waste are sent into grinders and shredders, which can be used to reduce the volume of this waste stream. Separating the different elements found in building waste streams is essential for enabling the recovery of useful materials, minimizing the amount of material sent to landfill, and allowing recyclable materials to find a new incarnation. Building materials such as bricks, metal, cardboard, drywall, concrete, paint, insulation, wood, glass, gypsum are considered for recycling operations in a new construction projects. However, other materials such as doors/windows, fixtures, appliances, wood/lumber, bricks, soil, HVAC equipment, architectural finishes are considered for reuse. Interestingly, there are advantages of onsite and off-site sorting of construction waste such that local contractors can oversee the sorting and profit from selling materials and reducing landfill fees, minimum staff training in required for off-site sorting in order to orient the team to waste separation.

However less space is required for off-site sorting where waste processing facility report can be used as documentation. The disadvantages of both methods are that it added onsite labour in sorting waste and other associated costs and a potentially limited pool of haulers who are prepared to go to the chosen recycling facility. It is important to consider cost implication for many local building contractors and typically resulting to net a loss to the contractor because labour costs are so high and the lack of revenue from the separate material (Wang et al., 2004). The project manager must consider how the project can be best managed to maximize recycling while the contract management determines technology, processes, and approach to recycling operations. The nature of construction/demolition project contract administration presents key challenges to increased recycling of C&D waste by a contractor.

Other issues include supervisory issues such as defining the execution of the recycling operation in accordance with the normal construction project objectives. Benefits of construction waste management include increase longevity of existing landfills, prevents costly process of siting new landfills, prevents emissions of air/water pollutants, conserves energy, stimulates development of greener technologies, and fully create job opportunities. Significantly, construction employees, project managers, architects and contractors all have a role to play in developing a management plan for construction waste management. Waste management specification should identify expectations, set diversion objectives, and define how construction waste management will be audited. These will allows the owner to satisfy himself that C&D waste is being properly recycled. For site operations, the contractor would be required to generate a form with weight tickets, signature and other forms of validation that reflect the kind and amounts of materials that have been recycled (WRAP, 2009).

## 2.4 Waste Management Hierarchy – The 3R's Concept

Waste management concept and level of hierarchy was first developed in 2007 by El-Haggar (El-Haggar, 2007) where the model produces an integrated approach in which options of waste management can be considered and thus serves as a systematic tool for those who generate and manage waste. Over the past few years a number of research studies have given the five key steps in the structure of Waste Management Hierarchy (WMH): reduce, reuse, recycle (3R's), recover and disposal (Peng et al., 2010; Hwang and Yeo, 2011).

The 3R's shown on Figure 7 represent the starting point of the waste level of hierarchy as explained by El-Haggar, and is commonly used to manage C&D waste effectively on sites as this often leads to composting, burning and non-recyclable residue sent to landfill. Addis (2006) affirm that when considering the option for reuse or recycling available for construction project, it is important to devise a Waste Management Hierarchy that will help decide which option will be most appropriate of the environmental perspective.

### 2.4.1 Definition

Waste management hierarchy is a nationally and internationally accepted guide for prioritising waste management practices with the objective of achieving optimal environmental outcomes. It sets the preferred order of waste management practices, from most to least preferred (Tam, 2011). Over the years, many countries reply on the waste management hierarchy, as guiding principles of achieve zero waste practices. The further activity mover up the waste management hierarchy, the more greenhouse gains there are to be made (Aadal et al., 2013).

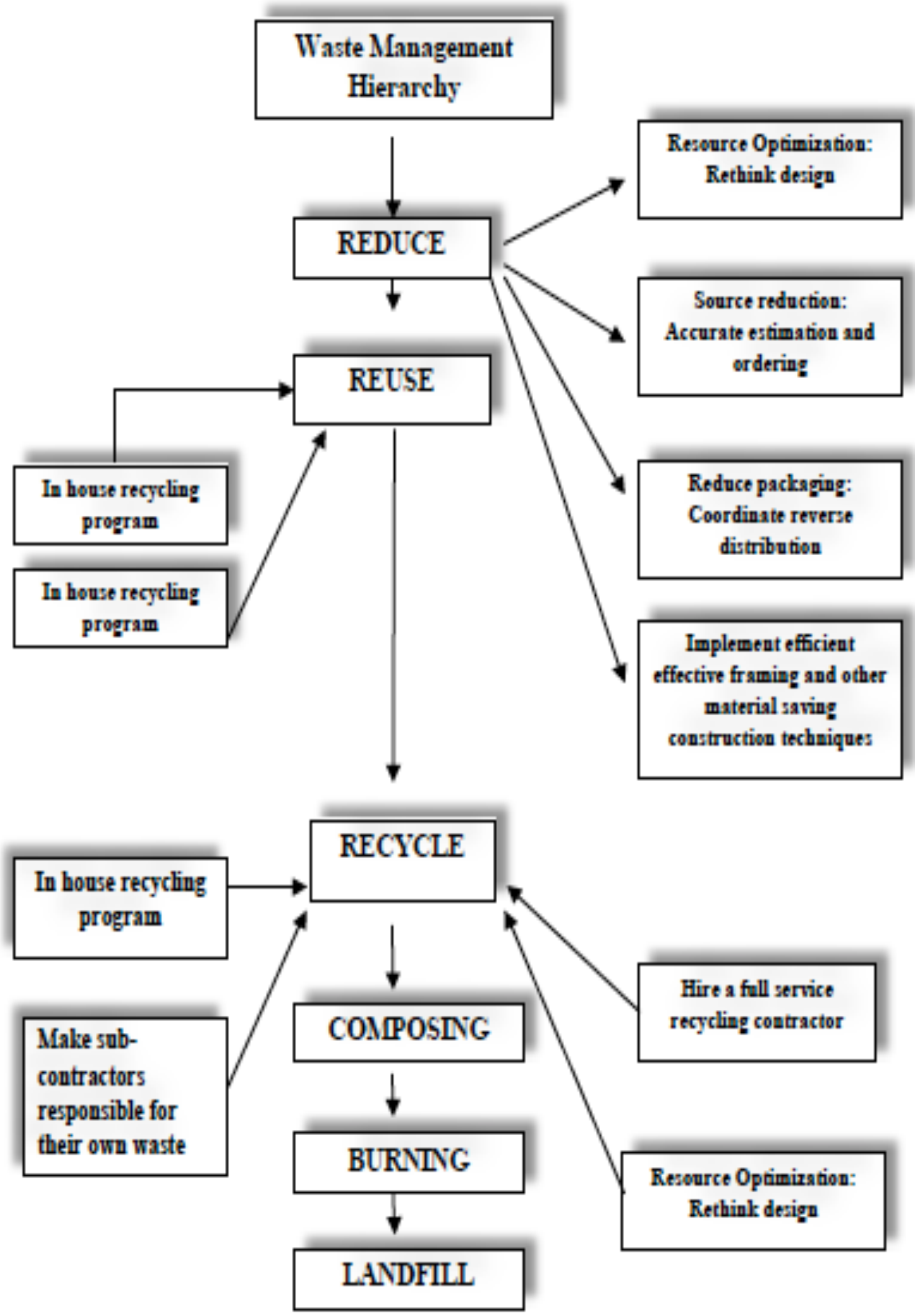


Figure 7: Waste Management Hierarchy (Source: Kibert and Lanquell, 2000)

### 2.4.2 Waste Minimisation

Managing C&D waste has become one of the major environmental problems in the world. Large amounts of waste have been generated from ongoing new construction works, as well as refurbishment and demolition works. Waste management covers the collection, transporting, storage, treatment, recovery and disposal of waste (Hao et al. 2008; Hwang, 2011; Guerrero et al., 2012). According to Poon et al. (2001) on-site sorting of construction and demolition are two of the most effective and reliable techniques to manage C&D waste. C&D waste is made up of both inert (soil, bricks, concrete etc.) and non-inert waste such as plastics, glass, wood, paper etc. (Zhao et al., 2010).

The separation techniques often attract advanced technology options and legislative control. Waste management concept is guided by level of hierarchy explained by El-Haggar (2007) as shown in Figure 7. This model produces an integrated approach in which options of waste management can be considered and thus serves as a systematic tool for those who generate and manage waste (Hwang and Yeo, 2011). Interestingly, the process of waste minimization can enhance high competition among local contractors through reducing production cost and creating better company profile. Conversely, only a few local contractors had focused on the impact of waste on the environment and have created the idea of recycling construction and demolition waste in a number of municipals (Tam, 2011).

Apart from the two benefits (i.e. economic and the environment), waste minimization can also contribute positively to the following: reduction of landfill spaces, enhance resource management and improve productivity and quality management (Zhao et al., 2010). Waste minimization and management on projects will help reduce the significant quantities of construction waste sent to landfill. More efficient use of building material would make a major contribution to reducing the environmental impacts of construction including reducing demand for landfill and the depletion of finite natural resources. Major improvements in building materials efficiency are possible without increasing costs by minimizing the overall creation of waste resulting from inefficient design and also reducing the quantity of material sent to landfill during the construction process through effective waste management (WRAP, 2009).

### 2.4.3 Reuse

Most C&D waste can be reused after demolition works. Reduction and reuse are the most effective ways to save natural resources, protect the environment and save money. Other benefits of reusing building waste is to reduce green house gas emissions that contribute to global climate change, help sustain the environment for future generations and to allow products to be used to their fullest extent. Many building materials can be salvaged from demolition and renovation sites and sold, donated, stored for later use, or reused on the current project. Typical materials suitable for reuse include plumbing fixtures, doors, cabinets, windows, carpet, brick, light fixtures, ceiling and floor times, wood, etc.

The question to consider is what C&D materials cannot be reused or recycled. It is believed that certain portion of the materials from construction and demolition projects are toxic or classified as hazardous waste. Materials generated in new construction that may require special handling include latex paint, chemical solvents, and adhesives. The age of structure involved in demolition projects ranges considerably (Tam, 2011). A number of older buildings may contain materials that are no longer allowed in new construction, such as asbestos and lead-based paint. It is important to recognize that the sustained growth in reuse efforts, as well as the sustained interest of the reuse industry, derives in large measure from the solid waste reduction hierarchy: reduce, reuse, and then recycle.

#### 2.4.3.1 Reuse Issues with Building Materials

Reuse and recycling of C&D waste is a growing area of interest across the world. Reuse is a means to prevent solid waste from entering the landfill, and recover resources. The construction industry is under increasing pressure to become sustainable. One of the ways to address this is through the use of reclaimed materials. Reclaimed materials are those that have been previously used in a building or project, and which are then re-used in another project (Mine and Tsutsumi, 2005; Kralj and Markic, 2008; Gray, 2015). Despite the usefulness of reclaimed materials and the benefits of reusing building waste, there are some underlying issues with building wastes that can be reused or recycled.

Following Addis's suggestions (2006) on reasons why reuse and recycling building materials is important one can clearly understand that the modern approach to 'reuse' and to 'recycling' is centred around the material lifecycle, environment, the benefits derived from building projects and the reputations of many construction professionals.

Addis (2011) suggested that when considering the various options for reuse or recycling available for a project, it is important to develop a hierarchy that will help decide which option will be most appropriate from the environmental point of view. According to local regulations, all construction and demolition materials, hazardous or toxic materials should be removed and managed (Khoramshahi et al., 2007). It is assumed that a certain portion of the construction and demolition materials is considered to be hazardous and or toxic in nature.

Hazard and toxic materials include latex paint, chemical solvents and adhesives and policy and legislation in England and in EU context require that environment concerns must be given great attention in terms of pollution and health effects (Construction Resources & Waste Platform, 2009). It is believed that latex paint can be planed, removed, and recycled at a lead smelter or disposed of appropriately, while the other building components can be reused (Dolan et al., 1999). Challenges with reuse of building materials is that sometimes more difficult to work with, local contractor familiar with reuse are hard to find, and may not be able to find what they are looking for. Building materials might be unable to be reused if they are considered dirty/take a lot more work.

#### 2.4.3.2 Benefits of Reusing C&D Waste

Using reclaimed building materials can significantly reduce these environmental impacts, and save up to 95% of the embodied costs by preventing unnecessary production of new materials, and reducing the amount of waste sent to landfill. Recycling and reuse of buildings and materials can yield significant economic and environmental benefits. Reuse of C&D waste promotes historic preservation, conserves both energy and resources, and contributes to the local economy. Building-related activities (demolition, remodeling and tenant improvement, new construction and land clearing) generate construction, remodeling and demolition (CR&D) waste.

Economic and environmental benefits of reuse of C&D waste include marketing opportunity for major companies, cost savings for builders, job creation, reducing energy use, contribution to climate change, and preserving embodied energy. Reuse of C&D waste help save money by reducing project disposal costs and eliminating the need for new materials for civil works (Kumbhar et al., 2013). It is important to recognise that the sustained growth in reuse efforts, as well as the sustained interest of the reuse industry, derives in large measure from the solid waste reduction hierarchy: reduce, reuse, and then recycle. It is best to reduce first, reuse as a second option, then to resort to recycling.

### 2.4.4 Recycling

Materials can either be recycled onsite into new construction or offsite at a C&D processor. Typical materials recycled from building sites include metal, wood, asphalt, pavement (from parking lots), concrete, roofing materials, corrugated cardboard, and plasterboard. Concrete with rebar can be crushed and separated for recycling. However, the recovery of C&D waste consists of collecting and sorting the material prior to delivery to a reuse or recycling facility. Recovery strategies include source separation, time-based removal by a hauler, and off-site mixed-solid waste processing at a recovery facility.

By recycling building materials on construction site or in the nearer region finally big quantities of CO2 are saved which otherwise would be released by removing waste and supplying natural building materials recurrently over large distances. There are a number of benefits to C&D recycling and these include reduction of the production of greenhouse gas emissions and other pollutants by reducing the need to extract raw materials and ship new materials long distances. Also, it conserves landfill space, reduces the need for new landfills and their associated cost as well as saves energy and reduces the environmental impact of producing new materials through extraction and manufacturing processes.

Recycling operations also saves money by reducing project disposal costs, transportation costs, and the cost of some new construction materials by recycling old materials onsite. Significantly, recycling tends to create employment opportunities and economic activities in related industries. There has been huge market for quality-assured recycled building materials. So far recycled building materials have been used in the construction of roads, foundations, and sports grounds, for noise protection walls, earth banks and in landscape construction.

#### 2.4.4.1 Recycling Issues in Building Materials

Recycling is considered as the reprocessing of a reclaimed waste material and converting it into a new material or use. Despite the benefit of recycling of building waste material, there are underlying issues with material usage in recurrent times. Recycling C&D waste is hardly a new concept for the construction industry. Building materials such as concrete and paving materials have been reused as fill material or roadbed over the years. Hazardous, toxic substances such as asbestos, lead, volatile organic compounds, solvents and adhesive are common building components. These materials are dangerous when they became degraded, distributed or airborne during construction, demolition, and reconstruction activities in building adaptation and during maintenance. There are some challenges with C&D recycling where people don't know whom to call and there isn't enough room on job site.

Conversely, it is possible for haulers to give impression of recycling initiative and actual not performing the actual recycle activities. It is imperative to understand that recycling process isn't about 100% perfect and not all materials get recycled in practice. There are a number of reasons besides the cost of disposal for the increase interest in recycling C&D waste. The cost savings from reducing cost of transporting virgin aggregate and reduction of asphalt cement requirements. For example, ferrous metal such as steel has also been extensively recycled over the years. However, steel and other metals generally often do not lose their physical properties after re-smelting (Kumbhar et al., 2013).

A number of steel mills incur higher prices for operations relating to shredded scrap metals and its recycling activities. In 2005, 13 million tonnes of metal was recycled in the UK and around 40% of this was used in the UK, and that remaining 60% exported worldwide (BMRA, 2010). From a recycling viewpoint, the more the material reused, the fewer resources are consumed. Dolan et al. (1999) argues that conventional recycling operations show that the amount of resources and capital equipment involved can be placed in a hierarchy:

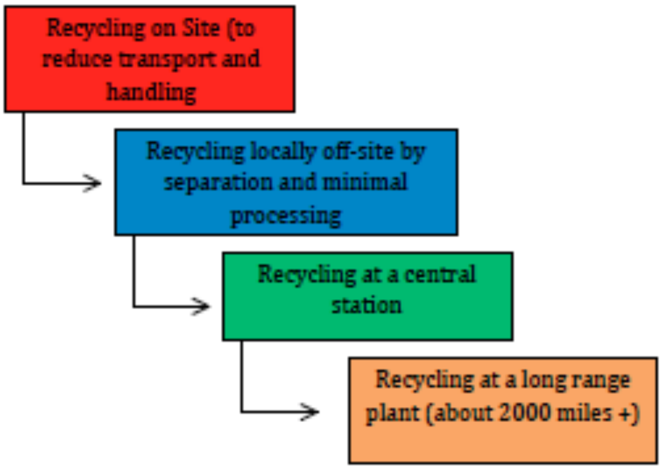


Figure 8: Resource level for conventional recycling operations (Source: Doland et al., 1999)

Managing construction and demolition waste onsite is a complex and challenging activity. A number of barriers and opportunities exist in developing strategies of waste reduction on construction sites. Some of the problems with managing waste in construction is the increase in management and recycling operation costs, lack of government legislation control, environmental impact, lack of trained staff and expertise, lack of reuse and recycling incentives etc. The increase in recycling operation cost may be the major concern for local contractors and other recycling consultants. Significantly local and regional authorities often face challenges with applying the waste management hierarchy approach.

Other key issues found with C&D waste recovery process include: waste management strategy implementation process with coherent process where it started at direct management without the property level of hierarchy, lack of data available on waste management strategies must be overcome and extensive monitoring requirements must be met to successfully implement the waste programs. Among other challenges found in material recovery processed are: effective enforcement and control of sound business plans and practices to established and applied to maximize economic and environmental benefits as well as lack of administrative capacity at regional and local level such as lack of funding, information and technical expertise must be overcome for effective implementation and success of policies, practices and procedures (Isnin and Sh. Ahmad, 2012).

#### 2.4.4.2 Barriers to Recycling Operations

The key barrier to promote recycling of C&D waste stream is the variability of supply for recyclers. The overall financial success of any recycling operation is dependent on the amount and quality of the supply of feedstock. Most waste processors will not make enormous commitment of capital unless a consistent quantity and composition of waste can be guaranteed. The variability of C&D waste is due to a number of contributing factors such as inconsistent composition of C&D waste, widely dispersed C&D waste activities; varying C&D waste management regulations, range of disposal options, including prevalence of illegal or unregulated disposal to landfill, and varying costs of traditional landfill disposal.

The nature and quantity of waste varies significantly. Construction and demolition waste includes various materials such as concrete, glass, wood, plastics, cardboard/paper, metal, rubber, rock pile, any of which can be expected from typical residential, commercial or institutional projects. It can be argued that the physical composition of some building materials constantly changes depending on such factors as the age of the project, availability of resources, and demolition practices. Significantly, contamination remains a major challenge to recycling. Mixed building waste is often difficult to sort if contaminated.

Hazardous materials such as asbestos or lead-based paint can be contaminated that waste and make it unusable as feedstock for other materials. Of hazardous waste streams are mixed with nonhazardous waste streams, the entire mixture must be treated as hazardous waste. Other barriers to recycling operations are legislation, local control and location of the project. Significantly, location of recycling projects plays a major role in the feasibility of C&D waste. Typically, materials are often transported to hoard enough material for a centralized recycling operation or to get to a recycling infrastructure. However, if the economics of recycling depend on the low cost of operation, the increased cost of transportation may impede recycling.

Waste management legislation and local control may have key impact on the consistency of C&D waste availability. Despite the availability of alternative recycling options and available technology, it is more cost-effective for local contractors to dispose of these materials onsite. Looking deeply in recycling operation a major barriers are the lack of recovery facilities, less capital investment, lack of markets, and the variability of the waste stream has resulted in few large scale and having many recyclers. The lack of recovery facilities means that, in many cases, local contractors have no storage for C&D waste regardless of the ability to separate C&D debris for recycling purposes.

#### 2.4.4.3 Benefits of Recycling C&D Waste

Construction and demolition waste are recognized as one of the largest components of the solid waste stream across the world. While much of this C&D waste is recycled for purely economic reasons, avoidance of landfill disposal of materials such as concrete, wood, metal, gypsum drywall and bricks has benefits well beyond financial ones. Interestingly, C&D waste recycling results in a greater job creation and industrial activity relative to landfilling. By avoiding the diversion of building waste to landfill, C&D waste recycling provides for a greater degree of environmental protection, a smarter use of natural resources, energy savings, and a net decrease in greenhouse gas emissions. Recycling C&D waste can help prolong building supply of natural resources and save money in the process. There are many benefits to the increased recycling of C&D waste.

On a wider spectrum, the recycling building materials conserves resources by diverting them from the landfill. For example, reclaimed concrete is often reused in new construction; a corresponding virgin concrete material is not consumed in that sense. The development of new markets for C&D waste often satisfies recycling activities as waster producers may also potentially have new sources of overall turnover.  Also, there are numerous cost benefits that are resulting from C&D waste recycling such as reduced overall project disposal costs, reduced transportation costs, reduced cost of new construction materials, reduced labour costs, and elimination of the need for new materials for road base and other civil engineering works.

#### 2.4.4.4 Incentives to Recycle

The provisions outlined in the environmental legislations (2010/13/EU- Energy Performance of Building Directive, UK Climate Change Act 2008, Energy Performance Certificates and Display Energy Certificates, Site Waste Management Plans, Environmental Impact Assessments etc.) in the construction industry has encouraged certain incentives and opportunities for recycling in the UK. Managing building waste efficiently will allow you first and foremost to meet your environmental responsibilities. Cutting the amount of C&D waste being diverted to landfill and reducing the quantities of raw materials used will contribute to the company's corporate social responsibility.

There are both direct and indirect incentives to promote the amount of recycling by local contractors, recyclers and waste producers.  Directive incentives are those that apply specific strategies to directly achieve recycling objectives. Such incentives apply directly to the amount or C&D recycling operation conducted by local contractors. The end of landfill for disposal has increased the awareness and the need for reusing and recycling building waste on a large scale. Restricting disposal options any also boost the amount of unregulated and unpermitted disposal of building waste. On the other hand, indirect incentives relate to the development of procurement standards for recycled-content building materials, including specified percentages of product, constituent materials, and discouraging landfill disposal.

The UK Government work in partnership with local authorities and businesses in all parts of the economy to encourage and spread best practice in waste prevention and resource management, and so reap the economic and environmental benefits for society and the economy. The government has driven innovations in the waste sector through signaling long-term ambition for waste minimization. They have provided relevant legislations to demonstrate leadership and best practices in waste prevention and management across the country.

### 2.4.5 Reduce

According to the guidance entitled "*reducing your construction waste*" released by WRAP (2009) the waste hierarchy is the starting point of reducing the amount of waste created by construction activities. The hierarchy advice that waste can be reduced, reused, recycled and disposal following a systematic top-down approach. It follows that first, it is important to reduce the amount of waste created, if created, then it is imperative to identify ways to reuse the materials and finally, if material cannot be reused then it is important to collect them to recycle and further advice that disposal is the last resort to managing C&D waste.

WRAP report (2009) pointed out the benefits of reducing waste such as generating income from collecting some materials, reduce costs from purchasing less material and maximising skip space, reducing CO2 emissions and by complying with local legislation. This report concluded that the best environmental and cost effective solution is to reduce the amount of waste produced in construction activities by early design consideration, using standard sizes and quantities of materials, minimise rework from errors and poor workmanship and plan ahead to reduce off cuts.

### 2.4.6 Disposal

The disposal is the last resort in managing construction waste. This aspect also remains the lower level of the waste management hierarchy. Doing traditional demolition, remodeling, or construction works, there is always the time sensitive and costly process of getting rid of leftover construction debris. Concrete, wood, steel, tiling and drywall all can be extremely difficult to haul off of a construction site. Except for items or materials to be salvaged, recycled, or otherwise reused, remove waste materials from project site and properly dispose of them according to Government regulations. In recent years, construction industry awareness of disposal and reuse issues has been recognized to reduce volumes of construction and demolition waste disposed in landfills (Napier, 2012).

A number of opportunities exist for the beneficial reduction and recovery of materials that would otherwise be destined for disposal as waste. Construction industry professionals and building owners can educate and be educated about issues such as beneficial reuse, effective strategies for identification and separation of wastes, and economically viable means of promoting environmentally and socially appropriate means of reducing total waste disposed.

## 2.5 The Roles of Waste Management

Waste management has plays a key role in the construction industry. Waste producers are required to effectively manage waste as they are considered as the person actually doing the work that produces the waste. Responsibility for waste management in England and Wales is split between the Environment Agency, as waste regulator, and local authorities in their roles as Waste Collection Authority and the Waste Disposal Authority. Unitary authorities control both aspects of collection and disposal.

### 2.5.1 Role of Designers

Designers such as architects, civil engineers, technicians are required to design building following guidance from the WRAP “design out waste” (WRAP, 2009). Designers should consider standard sizes, densities, positioning and height to enhance the process of waste minimization and primarily to achieve cost savings in construction. Recyclable building materials are required to be incorporated in design at the early phase of design and construction. Architects have a major role to play in providing the right specifications when designing out waste. This approach presents a proactive target options to reduce waste, recognizing that some key solutions on a project are most likely to achieve waste minimization, along with cost savings, carbon reduction and other related benefits.

### 2.5.2 Role of Clients

Clients play a major role in ensuring waste management and promote effective interaction between main contractors and sub-contractors. The client’s role is to demonstrate leadership by setting requirements for the efficient use of materials, communicate requirements on waste to the project team, ensure that waste issues are considered an addressed and ensure that all parties fulfilling their roles in the effort to reduce C&D waste (Ofori, 2007).

### 2.5.3 Role of Contractors, Sub-contractors and Suppliers

Significant volumes of waste result from activities such as inefficient design, inaccurate materials estimates and orders, design changes, poor logistics and storage, and a traditional low prioritization of materials costs (as compared to labour costs). Sub-contractors have an important role to play in eliminating or reducing wastage generated by these activities (WRAP, 2009). Whilst main contractors can ensure that waste is recycled effectively (where possible) it is the sub-contractors who have the ability to make real reductions in the total volume of waste generated. The main opportunity to achieve this is in producing accurate and realistic estimates of materials requirements and their associated waste and actively looking for ways to reduce C&D waste.

The main contractor’s role to deliver the clients requirements by developing a site waste management (SWM) plan, which has clear estimates and targets of waste that will be generated; has a clear strategy to reduce the waste and has a clear strategy to ensure the recycling of residual waste is maximized. The sub-contractors’ /suppliers’ role is to therefore support the main contractor in delivering the client’s requirements. These roles include: producing accurate waste estimates for their trade and supplying this information to the main contractor for the SWM plan. The best practice approach to waste reduction can be achieved by sub-contractors through effective planning, implementation, review and improvement (Tilaye and van Dijk, 2014).

### 2.5.4 Achieving Zero Waste In Construction

Zero Waste refers to waste management and planning approaches, which emphasize waste prevention as opposed to end of pipe waste management. It is a whole systems approach that aims for a massive change in the way materials flow through society, resulting in no waste. The ultimate goal of achieving zero waste is to eliminate waste or its disposal in landfill by encouraging waste producers to reduce their consumptions of resources as well as reuse and recycle materials. According to Jennings (2014) zero waste is a philosophy that encourages the redesign of resource life cycles so that all products are reused. Zero waste can represent an economical alternative to waste systems, where new resources are continually required to replenish wasted raw materials. It can also represent an environmental alternative to waste since waste represents a significant amount of pollution in the world.

Waste management plays a major role in achieving zero waste; however the ultimate approach to achieving zero waste is by designing for waste at the early stage of design (Moore, 2015). Designing out waste in construction, maintenance and refurbishment of buildings often result to eliminating a reasonable amount of waste. Design out waste is an interesting aspect of waste management and a way to achieve zero waste within the construction industry (WRAP, 2009). Designers play a key role in helping to deliver projects that are sustainable in terms of their environment, social and economic impacts. Designers have contributed in reducing construction waste by implementing five key principles such as design for reuse and recovery, design for offsite construction, design for materials optimization, design for waste efficient procurement; and design for deconstruction and flexibility.

### 2.5.5 Economic and Environmental Benefits

Waste management plays a major role in achieving economic and environmental benefits. Significantly, proper construction waste management will provide both economic and environmental benefits. A number of construction firms as well as the environment at large will benefit through the cost reduction process involved in waste management. The economic and environment benefits expected from waste minimization are relatively essential as it drives towards the opportunity seen in recycling and the possibilities of selling secondary waste materials as well as the meeting targets on reducing the number of C&D waste being diverted to landfill (Tam and Tam, 2006).

Although the transfer of waste to landfill often attracts associated fees/charges and this can be minimized if only waste stream from construction are effectively managed. Working effortlessly to prevent waste, promote recycling, and develop markets for valuable products have been top priority of waste users in the construction industry. In terms of good business: resource efficiency can be achieved by cutting costs and improving overall material efficiency. This often results to exceed expectation and meeting customer demand for sustainable business practice. Environmental benefits of managing construction waste relate to best use of raw materials, cutting down $CO_2$ emissions and reducing waste going to landfill. Waste management often complies with legislative control and local requirements ensuring that the process of reducing, reusing, and recycling of construction and demolition waste.

The UK waste legislation and EU Waste Framework Directive have giving direction on how to effectively manage waste with the use of the waste management hierarchy and the development of waste management plans. The introduction of the waste management had giving many waste producers and recyclers that the opportunity to meet relevant legislation and local requirement in construction waste handling. The Waste (England and Wales) Regulation 2011 gave provisions to general use of waste, the development of waste prevention programmes, aim monitoring, and evaluation of the programme. Other element of this legislation includes waste management plans, duty in relation to the waste hierarchy, duties in relation to waste management and improved use of waste as a resource.

## 2.6 Economic Aspects of Building Waste Material

The economic benefits to be gained from waste minimization and recycling are enormous. Calculating the costs of reuse and recycling and other diversion activities and comparing them with the disposal costs, a few studies also discussed the direct and indirectly and indirect impacts of an increased level of waste diversion on the number of jobs created and sales of secondary (recyclable) materials (Meyer, 2007; Jain, 2012; Srour et al., 2012; Liu and Wang, 2013).  Srour et al. (2012) argue that recycled materials directly create many jobs and it is considered to be cost effective in operations. Damuth (2010) identifies a number of requirements for estimating economic impacts of recycling building waste materials. These requirements include output of the economy, jobs creation and opportunities found with recycling operations.

What is even more important is how C&D wastes are generated. The costs associated to C&D waste generation has created issues such as high rate of waste disposal and inconsistencies in achieving a viable economic and environmental process of managing C&D waste. However, the cost saving in relation to recycling and reuse of C&D waste can be realised when the avoided cost of disposal, reductions processes and the potential revenue from the sale of recyclables are factored into the overall equation. The economics of recycling C&D waste remains a sensitive aspect of waste management strategies and procedures. This cannot be discussed without first stating a few fundamental facts. Interestingly, in a free-market economy the commodity prices are mostly determined by conventional demand and supply.

In recent years, the reuse and recycling of C&D wastes for obtain from the main components of residential and commercial structures appear to be making continuous progress (Wang, 2013; Hunt and Shields, 2014; Ahankoob, 2015). The benefits of reuse and recycling of waste streams from building construction and demolition include diversion of waste materials from landfill sites and reduced depletion of natural resources. Procedural and economic factors and the relevant standards that underwrite to the success of reuse and recycling are identified. Economic barriers include the need for rapid demolition and clearing of the site, the cost of separating the material to be recycled from contaminating materials and the relative economic advantage of disposal versus recycling. The economic feasibility of a recycling program often depends on whether the added cost (time, effort and resources/equipment) associated with the recycling activities is less than the avoided costs (tipping fees, labour, haulage, maintenance, taxes, and local permanent fees) (Duran et al., 2006; Begum and Siwar, 2006; Meyer, 2007; Srour et al., 2012; Calvo et al., 2014).

According to Nisbet et al. (2002) the economics of reuse and recycle of C&D waste lies with the capital investment in equipment to produce secondary material. The economic aspect of reuse and recycling of building materials are greatly considered by the following contributing factors: abundant and constant supply of demolition rubble, high dumping costs obtain from demolition rubble, easy access for heavy trucks, suitable industrial land available, preferably next to sanitary landfill and the ready market for secondary materials (Pacheco-Torgal et al., 2013). The extra cost of preparation, processing, inspection, storage and sale of building materials may result in their production costs being higher then traditional virgin material.

The landfill charges for demolition debris can make the difference between competitiveness of the recycled materials, which often depends on the required quality of the material produced. The economic feasibility of reuse and recycling operations depends on whether the added costs which includes time, cost, effort and equipment associated with recycling operations are less that avoided costs which include tipping fees, labour, hauling fees, maintenance, permit fees and taxes as well as sales turnover (Dolan et al., 1999). It was argued that if the added costs exceed avoided costs and turnover, the operation should not be allowed to continue or undertaken. However, it is critical that a thorough economic analysis is carried out to determine whether or not a project should undergo recycling operation.

### 2.6.1 Market Opportunity for Reuse and Recycling

The idea of reuse and recycled materials (secondary materials) has brought huge opportunities to the construction industry in terms of the benefits of C&D material recovery rate. These benefits include reduction of the production of greenhouse gas emissions and other pollutants by reducing the need to extract raw materials and ship new material long distances. Other benefits include saving energy and reducing the environmental impact of producing new materials through avoided extraction and manufacturing processes.

A number of opportunities have been seen as a result of reusing and recycling of building materials, which include creating employment opportunities and economic activities in recycling industries (Zhao et al., 2010). Recyclable building materials such as drywall, cardboard, concrete, rock pile are typical examples of products that generate more profits (selling secondary materials for other construction activities) for demolition contractors. The reused and recycled building materials have a considerable amount to contribute in the resale market. The market for recycled and reuse materials has expanded over years especially in the developed countries such as Canada, US and UK.

The global construction industry uses many different types of materials in large quantities (Srour et al., 2012; Calvo et al., 2014; Hunt and Shields, 2014). This means there are many opportunities for construction and demolition projects to increase the amount of waste reused or recycled. The recycling market development initiative helps many construction sites to minimize waste, improve the carbon footprint of construction operations and create recycling manufacturing jobs. Market opportunities for C&D waste recycling and reuse considers key factors such as demand and supply-side.

Demand for secondary (recyclable/reusable) materials attracts new opportunities in the development of recycle-content and reused products. Supply-side on the other hand focuses on actions performed by local recyclers in relation to volume increase, dependability and quality of recovered materials. There are new opportunities or expanding existing markets for the sales of secondary materials (i.e. recyclable/reusable wastes) in recent years (EPA, 2014). There are huge market opportunities with recycled gypsum, which include new drywall manufacture, cement manufacture, and agriculture unused drywall can be returned to a supplier, donated or sold. Reuse large portions of existing structure during renovation, refurbishment and/or redevelopment works often extend the life cycle of existing building stock and also conserve resources, retain cultural resources, reduce waste and reduce environmental impacts of new buildings. It is important to increase the demand for C&D waste debris so that the end markets for the materials are developed.

### 2.6.2 Drivers behind Waste to Community – Waste as a Resource

Interestingly, when identifying market for construction and demolition waste, which is, diverted from waste stream it is important to perceive this process as critical part of the site management-recycling plan. Zhao et al. (2010) further suggested five key requirements to be considered in the marketplace: specifications, quantity, delivery conditions, price and commitment. Material specification is a very important and this should reflect the condition and the composition of the waste material to be offered.

Typically, reused and recycled materials are separated as majority have been salvaged from demolition and renovation sites and sold or subjected to resale in many instances (Dolan et al., 1999, Cunningham, 2001; Tonglet et al., 2004). It was argued that the market price for recyclable materials depends on the cost of storage, collection, transportation, and other costs of the workstation. Srour et al. (2012) argued that the demand for C&D waste materials depends on short-term factor as long as there is an availability of virgin material. They believed that the sparser a resource is, the more economically feasible the recovered materials are.

Interestingly, Tonglet et al. (2004) argues that the volume of waste increases yearly, as is total resource consumption. With the simple addition of future population growth, the increased social, environmental and economic stress from resource use and waste will only become worse. The increase volume of waste has important total cost implications for its disposal. The costs associated with disposal may include the following: ~~a~~ local landfill fee charges for limited capacity and the fees charged on cleaning-up unproductive areas created by waste. Thus, it is important that any external waste streams remaining after careful application of related charges should all be considered a useful resource at the local level.

Waste as a resource can be applied in any community as an important contribution to local economies and materials cycles. In a number of instances, waste creates new skilled jobs and contributing to social equity (Gunter et al., 2000). The use of waste as a ‘resource’ inside a facility to cascade difference uses if waste energy, and materials has increased over the past few years in all sectors due to many opportunities found within.

## 2.7 Waste Management Legislation and Policy

### 2.7.1 Waste Legislation in USA and Canada

In US, the Resource Conservation and Recovery Act (RCRA) was enacted by Congress in 1976 to protect human health and the environment from the potential hazards of waste disposal, conserve energy and natural resource, reduce the amount of waste generated, and ensure that waste are managed in an environmentally sound manner. RCRA gave provisions to solid waste regulation by designing *‘Subtitle D’* which regulates the management of non-hazardous solid waste. Subtitle D establishes minimum guidelines federal technical standards and guidelines for state solid waste plans in order to promote environmentally sound management of solid waste. RCRA Section D is design for planning, regulating, implementing and enforcement entities for the management of non-hazardous solid waste. The federal regulation exists for C&D waste is either classified as RCRA hazardous or RCRA Municipal Solid Waste (MSW). In Canada, the management of solid waste including hazardous waste and hazardous recyclable materials is a shared responsibility.

The federal government regulates international and interprovincial/territorial movements of hazardous waste and hazardous recyclable materials. The provinces and territories are also responsible for establishing controls for licensing waste and recycling operations and treatment facilities. At the federal level, the Canadian Environmental Protection Act 1999 (CEPA, 1999) provides the government with the authority to control the movement of hazardous waste, hazardous recyclable material and non-hazardous waste. The Government of Canada support Environment Impact Assessment, which is mandatory to be conducted both at the provincial and federal levels of government.

### 2.7.2 Waste Legislation in Australia, China and New Zealand

In Australia, the National Waste Policy (NWP) provides the solid waste laws and regulation, which is a new coherent, efficient, and environmentally responsible approach to waste management in Australia. NWP provides the national framework for Australia's waste management and resource recovery from 2010 to 2020. The overarching goals of NWP are to avoid the generation of waste, reduce the amount of waste (including hazardous waste) for disposal, manage waste as a resource, and ensure that waste treatment, disposal, recovery and re-use is undertaken in a safe, scientific and environmentally sound manner and to contribute to a reduction in greenhouse gas emissions, energy conservation and production, waster efficiency and the productivity of the land.

In China, along with urbanization, population growth and industrialization, the quantity of municipal solid waste (MSW) generation has been increasing rapidly. Waste management legislation in China follows the environmental protection law of the PRC (issued in 1989), Law of the PRC on prevention of Environment Pollution caused by solid waste (issued in 1995, amended in 2004 and circular economy promotion law of the PRC (issued in 2008). Other regulations include administrative regulations (i.e. hazardous waste, medical waste and e-waste) department rules (i.e. hazardous waste, municipal waste, recyclable waste etc.) and local regulations. There have been growing concerns about '*e-waste*', which account for about 20-50 million metric tons of global waste per year (EPA, 2011).

E-waste is described as discarded electrical or electronic devices disposed for reuse, resale, salvage, recycling or disposal and are known as the fastest growing waste stream in the EU (Sthiannopkao and Wong, 2012). The European Union has implemented several directives and regulations (i.e. Waste Electrical and Electronic Equipment Directive) that place the responsibility for "recovery, reuse and recycling" on the manufacturer and this made is easier to effectively manage e-waste. The municipal waste management (MWM) covers the 3Rs principle, charging system of MSW treatment and other related area. In New Zealand, the 2010 Environment strategy alongside the Waste Management policy was adopted by the New Zealand Government to address a number of environmental issues.

The Waste Management Policy encourages a 'waste generator pays' approach along the Waste Management Hierarchy by relying on the 3R's principle (i.e. reduce, reuse and recycle). Other legislation used by New Zealand Government are the Resource Management

Act (RMA used in 1991 and Waste Minimisation Act (WMA) 2008. The RMA legislation focused on environmental effects of human activities rather than the activities themselves. WMA 2008 is designed to encourage waste minimization, protect and the environment and provide wider social, economic and cultural benefits. The provision of the WMA 2008 include, waste disposal levy, product stewardship, waste minimization fund, role of local government and the waste advisory board.

### 2.7.3 Waste Legislation in the EU and the UK

The EU waste management legislation and policy has been a start point to EU environmental concern and effective management of waste in all EU states (Adjei et al., 2013). These cover two key elements: Legislative idea covering laws and ordinances on how to avoid, recycle, transport, and dispose waste. Implementation of relevant law and regulations shows the duty of care and responsibility on enforcement processes. This policy is set out in the community strategy for waste management. Although, the UK at its early stages of being part of the EU did not follow the EU common policy (Jordan, 1998), the ratification of the Single European Act (1986) and the Treaty of Amsterdam (1997) ensures that EU laws have supremacy over domestic laws in all EU state members.

According to Adjei et al. (2013) the UK C&D Waste Management Legislation and policy changes over the past two decades have been directed to modifying national legislation to meet the requirements of EU waste directives. As emphasised in the UK waste strategy, C&D waste management hinges on the waste hierarchy reflecting sustainability. The preferred order for effective management is prevent waste, prepare for reuse, recycling, recovering through energy recovery and other disposal techniques as stated on the hierarchy. The UK waste legislation is derived primarily from eth EU governance and switched into UK law including Environmental Protection Act 1990, Waste Management Licencing Regulations 1994. This legislation formerly applied in England, Scotland, and Wales, which cover collection, storage, treatment, and disposal of controlled wastes.

## 2.8 The Effects of Legislation

Waste management and appropriate strategies plays a key role in the construction and demolition waste stream. Approach legislation, policies, processes, and procedures are set to enforce the waste management hierarchy in recent times. Significantly, waste prevention has been considered over the years and appropriate legislation have successful helped achieve waste minimisation and prevention. Developed countries around the world often put in place appropriate legislation to enforce the waste reduction.

Waste management in the UK involves understanding and complying with a list of legislation and regulations. The EU Waste Framework Directive provides the legislative framework for the collection, transport, recovery and disposal of waste, and includes a common definition of waste. Waste laws are generally designed to minimize or eliminate the uncontrolled dispersal of waste materials into the environment in a manner that may cause ecological or biological harm, and include laws designed to reduce the generation of waste and promote or mandate waste recycling around the world.

### 2.8.1 Recycling in the United Kingdom

Recycling operations in the UK have grown rapidly over the past years. In 2013, about 44% of the UK's municipal waste was recycled, composed, or broken down by anaerobic digestion.  This is driven by the activities of the statutory authorities such as Local authorities and other regulatory bodies responsible for the collection of municipal waste and operates contracts, which are usually kerbside collection schemes. The 3R's concept (reduce, reuse and recycle) plays a major role in recycling operations across the country. The UK construction industry uses many different types of materials in large quantities. This means there are many opportunities for construction businesses to increase the amount of waste they reuse or recycle.

There are many benefits associated with recycling waste from your construction projects. Recycling waste reduces disposal costs and carbon emissions. It also helps you comply with environmental legislation and restrictions on what can be sent to landfill. Construction waste recycling is the separation and recycling of recoverable waste materials generated during construction and remodeling.  The construction industry uses many different types of materials in large quantities. In fact, it is the responsible of the 20% of all UK waste, equating to approximately 90 million tonnes sent to landfill every year.

A large proportion (75%) of this is recycled with only 25% going to landfill or being reclaimed (EISC LTD, 2012). This means that there are many opportunities for construction businesses to increase the amount of waste they reuse or recycle. However, recycling operations are generally considerable low-grade products. The potential for high-grade re-use of waste materials is enormous. Where a waste material is re-used in its existing state without significant processing or alteration, it is generally referred to as a reclaimed material as opposed to a recycled material.

## 2.9 Summary

All key sources in the available academic literature agree that there is a growing trend of building waste stream as a result of urbanisation in major cities and countries. Almost all literature found around this subject believed that there is a need for C&D waste to be diverted from landfill. There have been a huge academic interest in management strategies for C&D waste, particularly in areas of identifying the kind of materials to be reused or recycled, reduction of building waste sent to landfill, environmental and economic impact of decision made on 3R's.

Key issues found in recent academic literature can be seen in three perspectives. First, between 2010 and 2012 figures shows that C&D waste in the UK has reduced significantly as compared to 2008. However, the increase in soils and stones in 2010 due to excavation remains a major contributing factor for an increase in C&D going to landfill. Second, nearly all articles reviewed in the literature review agreed that reasons for reuse and recycling of C&D waste is as a result of building material lifecycle, environmental impact, economic benefits derived from building projects and the reputations of many construction professionals.

Almost all publications, articles, and peer review journals gave their unique contributions towards in the academic interest that surrounds C&D waste stream and its environmental and economic benefits. The limitations found within this literature shows that only a few number of research studies had focused on reuse and recycling of C&D waste and their economic impacts (Zhao et al., 2010; Srour et al., 2012). Few research papers criticised the rate of material recovery in many construction sites, however within the literature there are less attention on choice-based system for considering whether to reduce waste, reuse and/or to recycle.

Another issue found in the literature is the economic feasibility of reuse & recycling and environmental impact of these concepts. Few research studies have provided theoretical model to effectively manage the economic feasibility of recycling building materials (Peng et al., 1997; Zhao et al., 2010; Srour et al., 2012). These studies have difference approach to economic analysis of reuse and recycling techniques. The literature found within this area of studies focused on developed countries such as US, UK, Canada, France, Italy and Belgium and Netherlands etc. all publications were in agreement that the level of economic analysis depends on the scale and scope of the recycling base station.

Sadly, none of these studies focused on other key parameters such as technology options, environment impact for decision support optimisation mode for reuse and to recycle building material. There is urgent need to develop theoretical model to appraise the economic and environmental impact of reuse of building materials. However, there is a need for the research to focus more on changing trends in C&D waste management Legislation and policy, the viability of the SMWP 2008, material recovery, rate of recovery and the parameters for decision support for optimisation mode.

# CHAPTER 3: A Review of Available Management Tools

## Chapter Aim:

The third chapter builds on existing management tools found in literature. The tools are identified and analysed in depth with the prospect of using one or two of the tools to develop the decision-support framework for recycling and reuse of C&D waste. This chapter leads to the development of the framework discussed in Chapter 4.

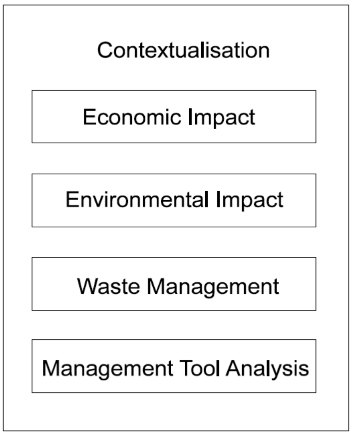


**Figure 9: Contextualisation II (Source: Designed by Author, 2015)**

## Chapter Objectives

- **Investigate** waste management tools in detail
- **Assess** the effectiveness of management tools for economic and environment measures.
- **Appraise** approaches in evaluating the economic and environmental benefits of recycling and reuse of C&D waste**.**

## 3.1 Introduction to Available Tools

This chapter will concentrate on the key tools, Multi-criteria decision analysis (MCDA), and Life Cycle Assessment (LCA), that are originally stated in Chapter 1. The selected tools are adopted to understand, describe and develop effective decision-support system for recycling and reuse of building waste. Thus, the two management tools play crucial role in the measurement of both economic and environmental benefits of waste management and decision-making process. A number of decision support models for waste management can be found in literature (Achillas et al, 2013; De Beer, 2013; Kiran and Rao, 2013; Karmperis et al., 2013).

The review of Kiran and Rao (2013) gave ideas of decision processes in various waste related fields. The article focuses on Multi-Criteria Decision analysis (MCDA) and Life Cycle Assessment (LCA). Karmperis et al. (2013) had a holistic view at various decisions support models and identified four models, where are Cost-Benefit Analysis (CBA), Multi-criteria decision analysis (MCDA), and Life Cycle Assessment (LCA). The selection of the management tools contributes to best feasible approach to assess the economic and environmental benefits of recycling and reuse of building waste as well as best tools need to develop a decision support framework.

## 3.2 Life Cycle Assessment (LCA)

The LCA is a popular tool used by a number of authors (Godfrey, 2008; Kijak and Moy, 2008; Tam, 2011; de-Beer, 2013). The tool is often used to investigate the potential environmental impacts, throughout a product’s life. The LCA approach is commonly used for a detailed environmental evaluation of various construction and demolition waste practices. There are limited studies on construction phase, material usage, and also discounting the significant environment impacts of construction. The LCA methodology is considered as a systematic environmental management tool that holistically analyses and assesses the environmental impacts of a product or process.

LCA focused on particulate matter, global warming potential and the motivation to ensure zero carbon. Research on environmental impact of buildings has primarily focused on material manufacturing, energy use during building operation, and waste management when decommissioning buildings (Gentil, 2011; Bilec et al., 2012). Onsite construction is often overlooked or incompletely modeled, leading to a gap in understanding the full spectrum of possible sources of environmental impacts form the life cycle of the built environment.

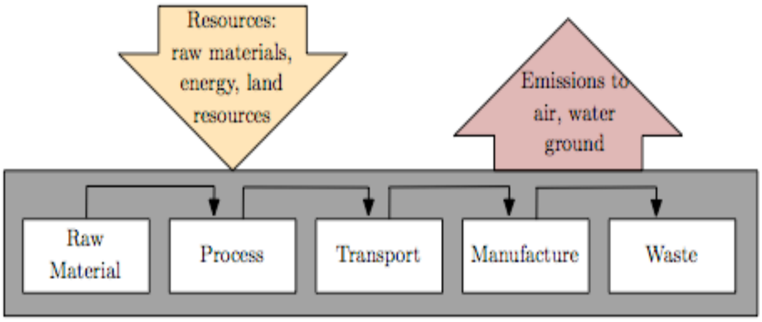
Bilec et al. (2012) argues that LCA can be used for decision-making that intrinsically promotes stewardship by considering global, national, and regional impacts on social and environmental problems such human health, resource weakening, and ecosystem quality. There have been a growing body of literature found for LCA in relation to environmental analysis of construction waste (Sara et al., 2001; Junnila and Horvath, 2003**,** Sharrad et. al., 2008; Banias et al., 2012, Kuikka, 2012; Coelho and de Brito, 2013).

A number of research studies believe that waste is produced in different types and quantities throughout the lifecycle of a building with the bulk of the waste produced from building operations such as construction and demolition phases and not necessarily that generated by building occupants (Duran et al., 2006; Tam, 2011). The lifecycle of a building can be determined by the use of materials and the waste generated throughout the building lifecycle. The most innovative approach to this is the challenge to reduce, recover, reuse, and recycle these waste that follow the variety of waste streams leading to landfill (Bilitewski et al., 1994).

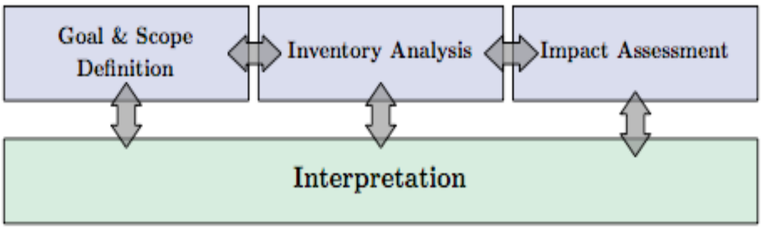
Equally, Junnila and Horvath (2003) considered the construction phase to include on-site activities and transportation for the development of LCA. Guggemos and Horvath (2006) and Junnila et al. (2006) developed model for construction. The models developed by Guggemos and Horvath (2006), Junnila et al. (2006) and Bilec et al. (2012) includes on-site energy, equipment utilization, transportation, and temporary materials. The model includes both the Life Cycle Inventory (LCI) and impact assessment stages. Process and IO methods are widely used and have strengths and limitations. Process LCA models the known environmental inputs and outputs by using a process flow diagram.

The guidance for the LCA assessment for selecting a modeling approach exists; the decision making process is based on the best available data and information. After considering the applicability of process only, and the range of hybrid LCA models, LCI was developed using an amplified hybrid approach. This modeling approach was chosen for the following reasons: to decrease reliance on the limited amount public data; to utilize available data within the context of the existing structure of the construction industry; and to ensure that the developed model has both depth and breadth (Craighill and Powell, 1999).

The hybrid LCA construction model blends the most important construction processes along with realistically assessing the availability and accuracy of data. An overall goal of the model was to respond to the construction industry's need to ultimately improve, in terms of sustainability, what it can control construction processes. Individual construction project has its uniqueness, the LCA model allows for project specific user input, for example, project cost, which is important for usability. The construction industry is driven by schedule and cost, so the framework of the model centers on those two factors.



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



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

**Figure 10: A standard life cycle model and procedure (Source: Baumann and Tillman, 2009 and Mihelcie et al, 2010)**

The LCA model consider input and output through building material as raw materials, processing this materials such as reuse or recycling and transporting this materials and resulting into an output (i.e. emission of $CO_2$ to air water and ground). LCA procedure involves goal and scope definition followed by inventory analysis and lastly impact assessment will be carried out and show in figure 8. A LCA model and procedure is shown in Figure 10 (a & b) providing the environmental inputs and impacts that is associated with a manufacturing life cycle. It is important to understand that ISO 14040 introduced in 1997 gave provisions for the first step in LCA model which defines the goals and scope followed by life cycle inventory analysis, impact analysis and finally the interpretation of results.

The goal can be made clear with specific research question, which leads to the expected outcome of the study. However, the scope states the function of the investigation, which is considered to the foundation of LCA. This function is adopted to incorporate all inventory and impact measures. Limitations are an important methodologies choice and involved the inclusion or exclusion of processes connected to a study. In terms of life cycle inventory analysis, a flow diagram and inventory analysis is designed and carried out. The inventory analysis includes a full description of all inputs within the defined limitations/boundaries of given products life cycle. With this in mind, inventory analysis tends to quantify all available resources, linked with each phase of the life cycle (Bilec, et al., 2012). First phase of the inventory analysis is to define the flow chart followed by data collected and finally, the different loads on the system that needs to be estimated. The development of the flow chart model is created within the system limitations as set out in the scope of the LCA assessment. However, the flow chart is developed indicating the activities and the flows within the system. This chart is adopted to assess where potential impacts are and how they affect the impact classification as defined in the scope (Baumann and Tillman, 2009).

**Table 3: Application of decision analysis for LCA steps (Literature survey compiled by Author, 2015)**

| **LCA steps** | **Authors** |
|---|---|
| **Goal and Scope Definition** | Miettinen and Hamalainen (1997); Michelcic et al. (2010); Boufateh et al., (2011); Kiran and Rao (2013) |
| **Inventory Analysis** | Werener and Scholz (2002); Benetto et al. (2004); Guggemos and Horvath (2006); Junnila et al. (2006) |
| **Impact Assessment**:<br>Classification<br>Characterisation<br>Valuation and aggregation | Hertwich (2001); Michelcic et al. (2010) |
| | Chevalier and Rousseaux (1999); Junnila et al. (2006) |
| | Benoit and Rousseaux (2003); Guggemos and Horvath (2006) and Junnila et al. (2006) |
| | Basson et al. (2000); Boufateh et al., (2011) |
| | Kiran and Rao (2013) |
| **Interpretations** | Geldermann and Rentz (2005); Michelcic et al. (2010); Boufateh et al. (2011) |

### 3.2.1 Methodological aspects of LCA model

The methodological aspects of LCA model are guided by underlying assumptions in relation to time horizon, the energy system, carbon estimate, and system boundaries. The time horizon has often raised a number of debates in recent times has the choice of time impact the overall outcome as well as it has greater influence of other impact categories. Disposal of waste and land acquisition are challenges in terms of time horizon (Gentil, 2011). This issue affect LCA model in terms of accountability for environment impact of products. Gentil (2011) argued that LCA model should consider a long-term carbon emission. Energy system is another aspect of methodological aspects of LCA has it is assumed that energy as a greater impact on the outcome of LCA.

A few studies have discussed the merits and demerits of the use of minimal electricity when modelling LCA for C&D waste (Basson et al., 2000; Junnila and Horvath, 2003; Boufateh et al., 2011; Kiran and Rao, 2013). It is evident that the choice of energy mix depends on the scale of the study and whether the study is a reporting or accounting exercise or a comparison between two systems. The final consideration for methodological aspect of LCA is the waste composition, which relates to three levels of composition waste fractions: primary, secondary and elemental (Gentil et al., 2010). The primary composition consists of paper, wood, plastics, concrete, metal etc. The secondary composition include newsprint, magazines, posters etc., and the elemental composition are physical and chemical properties of C&D waste e.g. lower heating value, thermal conductivities, mercury content etc.

### 3.2.2 Technical assumptions of LCA model

Technical assumptions of LCA were discussed in a study conducted by Gentil et al (2010) in relevance to the outcome of the LCA model. Figure 11 below illustrates the technical assumptions of waste management LCA model. This diagram shows that the choice of inputs parameters will have a huge impact on the overall outcome. However, key waste management process includes assumptions, technology type, and inventories adopted to provide the output.

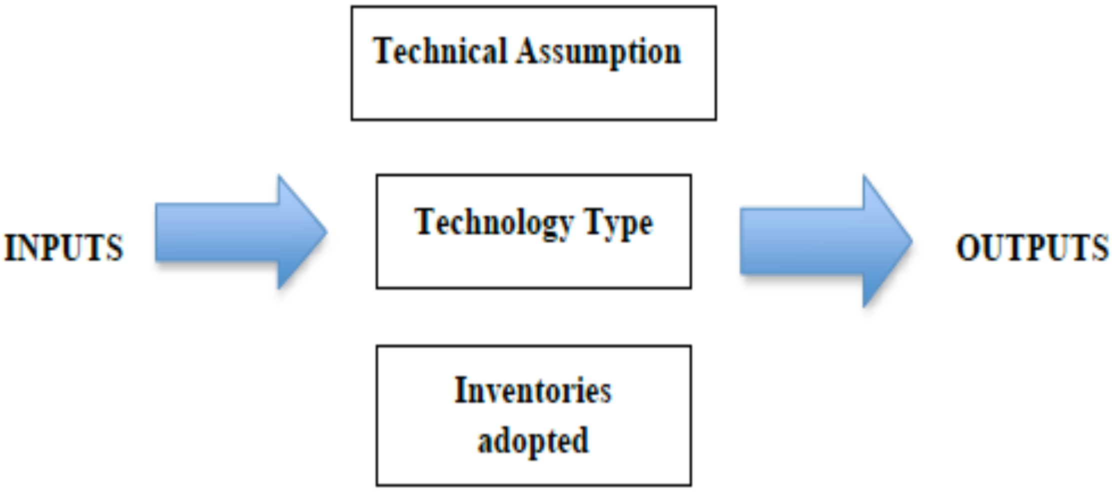


**Figure 11: Generic waste technology in LCA Model (Adapted from Gentile et al., 2010)**

The input parameters aside waste inputs include building materials such as water, lime, activated carbon, fuel oil etc. The process to treat the waste, with the intention to reduce carbon emissions, uses these parameters. Other input parameters to waste management process include construction, maintenance and decommissions (Bilec et al., 2012).

## 3.3 Multi-Criteria Decision Analysis (MCDA)

The multi-criteria decision analysis considers real world decision-making problems due to its complexities. The multi-criteria decision analysis has become a tool commonly applied to C&D waste management, allowing decision-makers to have a deep understanding of the problem, and supplies alternative course of action, form several viewpoints (Morrissey and Browne, 2004; Roussat et al., 2009; Marttunen, 2010; Achillas et al., 2013). Although recent studies have used multi-criteria decision analysis to investigate complex problems. The MCDA is considered in order to handle more than one set of data and help decision-makers to address the problems of waste generated on construction sites (Roussat et al., 2009).

Decision-making in environmental projects can be complex and seemingly intractable, principally due to the inherent existence of tradeoffs between sociopolitical, environmental, and economic factors (Linkov et al., 2004). MCDA not only provides better-supported techniques for the comparison of project alternatives based on decision matrices but also has the added ability of being able to provide structural methods for the incorporation of project stakeholders' opinions into the ranking of alternatives. Multi-criteria analysis establishes preference between options by reference to an explicit set of objectives that the decision making body has identified and for which it has established measurable criteria to assess the extent to which the objectives have been achieved.

### 3.3.1 Rationale for MCDA

The rationale behind MCDA is the ability to handle large and complete amounts of data. MCDA plays a key role as a potential tool for analyzing complex real problems due to their inherent ability to judge different alternatives (i.e. choice, strategy policy, scenario etc.) on various criteria for possible selection of the best or suitable alternatives. MCDA is a subjective tool, which allows the user to insert their own personal preference and guide in order to meet specific objectives. According to Dodgson et al., (2009) MCDA tool is used to access the different parameters, some of which cannot be expressed in monetary terms, or for which monetary values do not exist. The application of MCDA in relation to managing waste is well structured and the two common ones are Electre III and Analytic Hierarchy Process (AHP). Other types of MCDA are Simple Multi-Attribute Rating Technique (SMART), ORESTE and PRO-METHEE respectively.

### 3.3.2 Opportunities and Limitations

MCDA provides a clear and transparent methodology for making decisions and also offers a formal way for combining information from disparate sources (Boufateh et al., 2011). Sadly, not all MCDA tools provide comprehensive support in terms of decision-making; there are, however, others that offer substantial value (Dodgson et al., 2009) They further described the criteria used for selecting the appropriate MCDAs as: transparent, easy to use, data requirements that are consistent with the needs of what is being studied, probability to provide an audit trail and realistic resource requirements.

Finally, Dodgson et al. (2009) proposed the performance matrix, which incorporates weighting and scoring of options (higher the preference the higher the assigned score and less preferred options scores less) for all inputs as shown in figure 10. According to Dodgson et al. (2009) Multi-Criteria Decision Analysis is carried out by eight unique steps. Step 1 seeks to establish the decision context, step 2 identifies the options being appraised, step 3 identifies objectives and criteria.

Step 4 covers the scoring system which assesses the expected performance of each option against the criteria, step 5 is the weighting, whilst step 6 combines the weights and scores for each option to derive the overall value. Step 7 examines the results and finally step 8 presents the sensitivity analysis, which covers measurement of uncertainties within the MCDA model.

The limitations found in MCDA techniques are that personal judgment may be required and experience is required as well. Also, Morrissey and Browne (2004) argue that the allocation of weights under the MCDA model are subjective and often affect end results. However, the arrangement of complex policy problems as well considering the appropriate method such as MCDA model often leads to more informed and better decisions. However, Kiran et al. (2013) pointed out that MCDA model is a useful decision-making tool as also very complex to use.

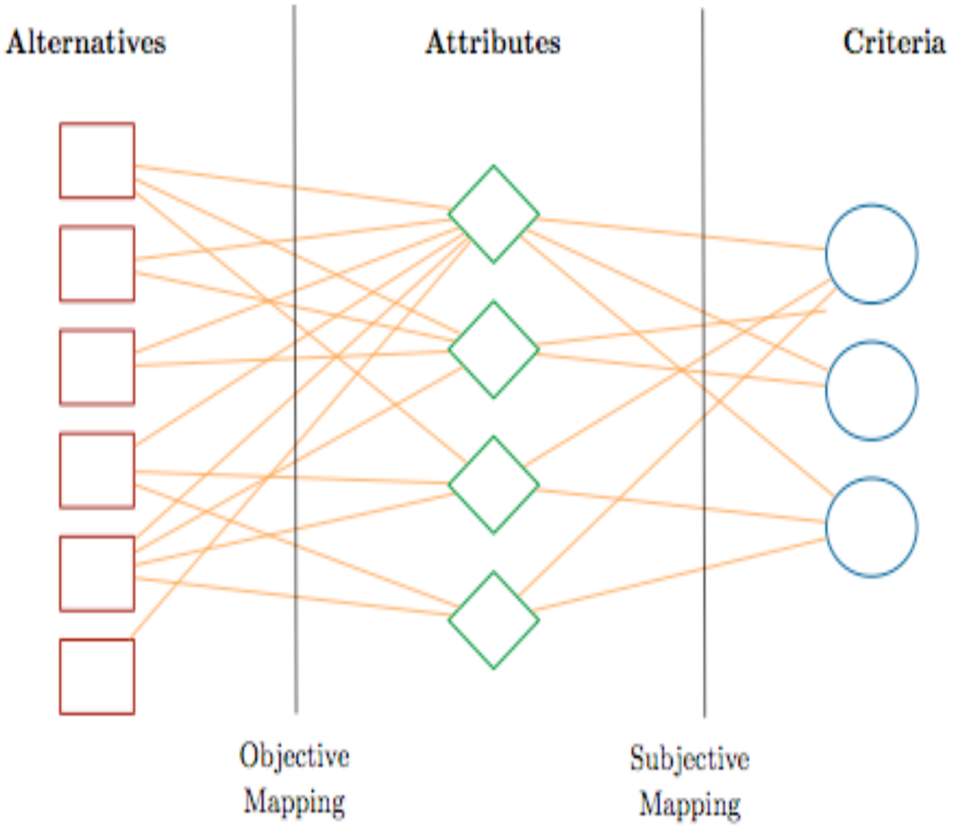


Figure 12: Alternative Attribute Criteria Mapping (Source: Nahman and Godfrey, 2010)

There are different methodologies to complete MCDA as suggested by three authors (Belton and Stewart, 2002; Dodgson et al., 2009; Kiran et al., 2013). Each author describe the generic steps of MCDA where there seemed to be a consensus among these steps. The following steps are found through literature shown in Table 4.

Table 4: Application of MCDA's steps (Source: Dodgson et al., 2009)

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

### 3.3.3 Addressing Uncertainties in MCDA

Dealing with uncertainties within the MCDA framework required careful assessment and consideration. As noted in Borhne (2013), Brinkhoff (2011), Nahman and Godfrey (2010), uncertainty is an important part when building a MCDA model. The common uncertainties in MCDA models are variations and lack of knowledge (de-Beer, 2013). However, uncertainties are divided into two elements: internal and external. External uncertainty deals with the lack of knowledge of information that is available when developing different scenarios.

On the other hand the internal uncertainty addresses the construction of the problem and its analysis. Not all ‘internal uncertainty’ can be solved whilst other challenges include ambiguity about the specific meaning of a criterion. This may lead to unclear choice of action leading to uncertainty in data outcome and lack of appropriate choice. However, Belton and Stewart (2002) identify possible solutions such as restructuring the entire model to the issue of ambiguity or false impression. They further suggested that there is a need to improve the parameters of the analysis and therefore repeat the process until they address the issue.

In dealing with the complexities of the issue of uncertainty in MCDA model, Step 8 (sensitivity analysis) as shown in Table 4 is an important step and tool to use in dealing with uncertainties (Triantaphyllou, 2000; Belton and Stewart, 2002). These authors suggests that sensitivity analysis involves key aspects such as impact of scores (relating to levels of uncertainty), weights within categories, weights between categories (such as relative importance of human health and safety, environment etc.) and finally the associated costs.

### 3.4 Using Multi-Criteria Decision Analysis with LCA

It is especially beneficial to combine LCA with multi-criteria decision analysis (MCDA) techniques to simplify understanding of trade-offs and multiple perspectives in the impact assessment. LCA is increasingly used as a decision-support system that enables the modeling, the evaluation and the comparison of different alternatives of building waste. Table 5 below compare and contrast the application of LCA and MCDA.

**Table 5: Comparison of LCA and MCDA**

| LCA | MCDA |
|---|---|
| Use to understand trade-offs | Use to understand trade-offs |
| Systematic environmental management tool that holistically analyses and assesses the environmental impact of a products to process | Considers real world decision-making problems due to its complexities. |
| Use weighting factors to calculate LCIA | Use objective and subjective mapping to determine choice-based decision |
| Tool that collects, organises, and evaluates quantified data useful for decision-making | Establish preference between options by reference to an explicit set of objectives that the decision making body has identified. MCDA is designed to address decision conflicts often seen among design criteria in waste material selection |
| Decision-support system (sometimes evaluation are unclear enough to serve the purpose of comparative LCAs, particularly to get the best alternative). | Clear and transparent methodology for decision-support system |
| Enables modelling, evaluation and comparison of different alternatives of products (C&D waste) | Analyse the results of LCA of products (C&D waste) i.e. MCDA can be used to interpret LCIA |
| Evaluate decision on economic and environment impact | Use for analysing difficult scenario on environment impact such as Global Warming Potential (GWP), Human Toxicity Potential (HTP) etc. |
| LCA thinking consists of a multi-criteria tool for global decision | Considers several criteria of different types (impacts categories) for global decision) |

Kiran and Rao (2013) stated that LCA is an analytical technique that quantifies the environmental and sustainability impact across a range of categories for products over its entire life cycle. According to Kiran and Rao, the main purpose of LCA is to study and compare different products to determine where they have their greatest environment impact. MCDA in this regard tends to gain its importance as potential tool for analyzing complex real problems due to their inherent ability to judge different alternatives (i.e. choice, strategy policy, scenario etc.) on various criteria for possible selection of the best or suitable alternatives. Sadly, there are a number of underlying issues with MCDA methods, which are found in the literature. Early research by Vincke (1989) categorizes these MCDA problems into three groups:

- *Multi-Attributes Utility Theory (MAUT):* practical examples of this model are SMART, UTA, AHP, and GP. These methods consist of aggregate of different points of views in a single function that is then optimized and they are considered to be complex in nature.

- *Interactive Methods (IM)*: MCDA method, which consist of interactive and iterative exploration of all alternatives. IM fit perfectly into problems with almost vast number of alternatives and can be merged other group.

- *Outranking Methods:* This method consists a pairwise comparison of alternatives according to each criterion with introducing indifference and preference thresholds. These thresholds interpret comparisons on an order of significance with the aim to structure a global preference between alternatives without compensation (partial aggregation). One interesting aspect of the outranking method is that each relationship, an index known as “degree of credibility” of outranking quantifies the control of one alterative over another.

- *Single Synthesizing Criterion Approach (Analytic Hierarchy Process):* This approach is a structured technique for organizing and analyzing complex decisions and is developed by Thomas L. Saaty in 1970. The AHP first decomposes the decision problem into a hierarchy of sub-problems. Then the decision-maker evaluates the relative importance of its various elements by pairwise comparisons. The disadvantage of this approach is that it has a rank reversal principle, which occurs when adding another option to a list of options that will be evaluated. There might be tendency that the reversed ranking order of two options might be unrelated to new option and this result to inconsistency about the evaluation process for AHP model.

Boufateh et al., (2011) support the use of the "*outranking methods*" due to its relevance in decision support system, which they argued that it should be intuitive and simpler to decipher. They further argued that the *outranking methods are* characterized by a good degree of practicality in the decision-making context. The Analytic Hierarchy Process (AHP) is an interesting tool often used to convert assessments, which are relatively subjective, and give them overall scores and weights. This method will be further considered and explained further on the methodology section of the thesis. Banar et al. (2008) point out that the usefulness of LCA in solid waste management options. They argued that LCA is used to demonstrate the performance of management alternatives in decision-making process, authorities, communities, industry and waste management companies in order to appraise the economic and environmental viability of reuse and recycling C&D waste.

There have been few studies, which consider the use of MCDA and LCA of solid waste management options (Banar et al., 2008; Ortiz et al., 2009; Ulukan and Kop, 2009; Dosal et al., 2013). By analyzing the positive and negative environmental effects of all kinds of projects or products, LCA has been used for several areas to analyze and to evaluate different alternatives. Huang et al. (2009) adopt LCA to evaluate environmental impacts of using recycled materials in asphalt pavements. The authors evaluated relevant LCA model can be used as a decision support tool for sustainable construction in the road industry. Other relevant LCA studies (Banar et al., 2008; Cherubini et al., 2009; Iriarte et al., 2009; Hsu, 2010) on construction waste management as the study of Cherubini et al. (2009) discouraged the diversion of construction waste to landfill in relation to environmental impacts.

### 3.4.1 Considering Suitable MCDA approach

With the varieties of MCDA techniques discussed earlier, we found guidelines for selection of MCDA in literature (Vincke, 1989; Guitouni and Martel, 1998; Ulukan and Kop, 2009; Fedrigo and Hill, 2001). Table 6 shows the guideline considered for the selection of MCDA tool. It is important to understand that this stated guideline helps many decision makers to evaluate the appropriate type of analysis suitable for the difference scenarios. However, this guideline is considered for the research work to help in the selection of suitable tools for building a decision support system for the economic and environmental benefits of recycling and reuse of C&D waste.

Table 6: Guideline for selecting MCDA model (Source: Ulukan and Kop, 2009)

| Checklist for MCDA model | Guideline |
|---|---|
| ✓ | Determine the stakeholders of the decision process. If there are many decision managers, one should think about group decision making methods |
| ✓ | Consider the cognitive nature of decision makers when choosing a particular preference clarification mode. |
| ✓ | Determine the key issues with decision identified by decision makers. If they will like to get an alternative ranking, then a ranking method s considered |
| ✓ | Choose the multi-criterion aggregation (MCAP) procedure that can accurately accommodate the input information available for which the decision makers can easily give the required information |
| ✓ | The compensation degree of the multi-criterion aggregation procedure is an important aspect to consider and to explain to decision makers if he or she refuses any compensation, then MCAP will be rejected. |
| ✓ | The fundamental hypothesis of the method I to be met (verified), otherwise one should choose another method |
| ✓ | The decision support system which comes with the method is an important aspect to be considered when the time comes to choose a MCDA method |

## 3.5 Summary

All key sources in the available academic literature agree that there is a growing trend of C&D waste stream as a result of urbanisation in major cities and countries. Almost all literature found around this subject believed that there is a need for C&D waste to be diverted from landfill. There has been a huge academic interest in management strategies for C&D building waste, particularly in areas of identifying the kind of materials to be reuse or recycled, reduction of building waste sent to landfill, environmental and economic impact of decision made on 3R's.

Conversely, few studies argued that decision-making system for managing building waste is considered by key management tools such as Life Cycle Assessment, Environment Impact Assessment (EIA), Risk Assessment (RA), and Multi-Criteria Decision Analysis (Achillas et al, 2013; De Beer, 2013; Kiran and Rao, 2013; Karmperis et al., 2013). These tools often give better clarity to waste problem and help decision-makers to provide lasting solutions. To address these key issues there is a need to use the right MCDA model amongst many existing once in order to evaluate the economic and environmental benefits of recycling and reuse of C&D waste.

The chapter has successfully explored the waste management tools (i.e. LCA and MCDA) and have discussed both opportunities and limitations for using these tools with the aim of building a realistic decision-support framework. However, there are gaps in the application of these tools in relation to showing some degree of clarity and transparency towards the end results. Constraints and methodological issues observed in the application of LCA and MCDA models will be further discussed in the conclusion chapter. Meanwhile, the next chapter focused on presenting the methodology and framework development.

# CHAPTER 4: Methodology and Framework Development

## Chapter Aim:

Chapter 4 presents the solution development and the research methodology, which set out to develop a combined framework using two management tools: MCDA and LCA.  The framework is developed to assist decision-making, based on the economic and environment benefits of recycling and reuse of C&D waste. The framework is to be created and applied to the two case studies discussed in Chapter 5.

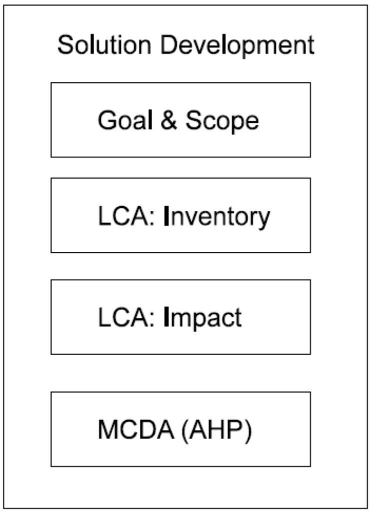


Figure 13: Solution Development (Designed by Author, 2015)

## Chapter Objectives

- **Examine** attributes to decision making in recycling and reuse of C&D waste
- **Develop** a decision support framework

## 4.1 Research Design

Following on from the problem statement discussed in Chapter 1, there are clearly key issues with C&D waste management in terms of economic and environmental measures. Chapter 1 suggested that two management tools (i.e. MCDA and LCA) could facilitate economic and environmental analysis as well as decision-making, providing effective management of C&D waste respectively. This chapter seeks to develop a combination of the two tools in order to analyse and develop a realistic decision support system for the recycling and reuse of C&D waste. A review of the available literature was undertaken in order to contextualise the problem and to analyse different approaches to the development of solutions.

Initially, the research reviews available literature which contains previous knowledge related to C&D waste generation, conceptualises the underlying principles of waste management, and addresses the issue of economic and environmental impact in relation to recycling and reuse of C&D waste. Chapter 3 features a detailed review of the LCA and MCDA models and presents a broad discussion on scope, definitions, opportunities, and limitations. The literature review helps the researcher to develop preliminary research questions, as well as in developing the null hypothesis outlined in Chapter 1.

The research is designed to address the current problem with managing C&D waste by considering the development of solutions through the construction of a decision-support framework. The design will attempt to address the proposed research questions and objectives. The methodology is designed to give a logical and insightful answer to the research questions, as clearly stated in the introduction chapter. Figure 14 below describes the methodology followed in this thesis.

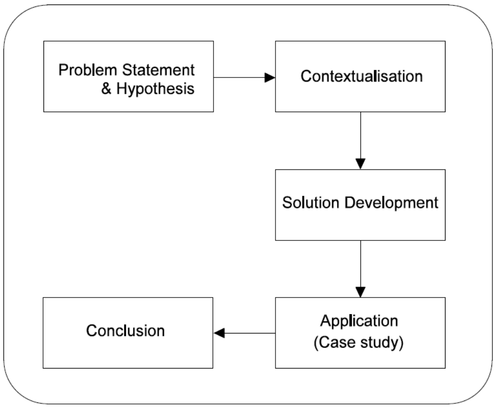


Figure 14: Research Design for developing framework (Source: Designed by Author, 2015)

The research considers the solution development and its application to a real-life case study in order to validate the effectiveness of the decision-support framework. A proposed solution is then developed and applied to two case studies in order to meet outlined research aim and objectives. The outcomes of the case studies are analysed in relation to the parameters set out in the proposed solution.

### 4.1.1 Revisiting Research Aim and Objectives

The aim of this PhD research work is to evaluate the economic and environmental benefits of recycling and reuse of C&D waste and to develop a decision-support framework for reuse of C&D waste. In order to meet this aim the study developed the following objectives:

- To evaluate the gap in the economic and environmental impact assessment of recycling and reusing C&D waste.
- To appraise approaches in evaluating the economic and environmental benefits,
- To identify the opportunities for recycling and reuse of C&D waste
- To investigate the legislative and other barriers for efficient recycling and reuse of C&D waste
- To develop an economic analysis of the recycling and reuse of C&D waste, including the economic value of the environmental benefits
- To examine decision-making regarding the reuse of C&D waste before arriving at a decision-support framework.

The research aims and objectives are revisited in this chapter in order to draw attention to the goal of the study. The activities carried out in terms of framework development and their application to the two case studies selected within the context of this research provide strategic ways to demonstrate the researcher's ability to meet the stated research goal and questions.

### 4.1.2 Qualitative Case Study Methodology

Qualitative case study methodology provides tools for researchers to study complex phenomena within their contexts. This approach facilitates exploration of a phenomenon within its context using a variety of data sources (Baxter and Jack 2008; Fink 2009; Yin, 2014). As a result of the complex nature of the research, the researcher has decided to include a case study as part of the solution development theme. An explanatory case study type was considered appropriate, since there is a need to seek answers to the preliminary research questions that explain the presumed causal links in real-life interventions; these are too complex for the survey or for experimental C&D waste management strategies.

The application of the decision-support framework to the two case studies has helped the researcher to validate the framework and to meet some of the objectives of the thesis. The two case studies, however, were selected based on the criteria set by the researcher: size, cost, and volume of work for new build and demolition projects.

## 4.2 Developing a Decision-Support Framework

The exploration of available management tools to aid the development of decision support system was captured on Chapter 3, which is an extension to the Chapter 2. Chapter 3 discussed the opportunities and limitations of LCA and MCDA and further suggested that AHP is an appropriate tool within the MCDA model to be used to develop a feasible decision support framework.

The purpose of Chapter 4 is to construct a decision support framework using MCDA and LCA. The proposed framework will start by evaluating the current state of C&D waste management process by adopting LCA tool and then consider policy based decision-making measure relying on AHP tool. The research considers a four-phase process as show in Figure 15 below.

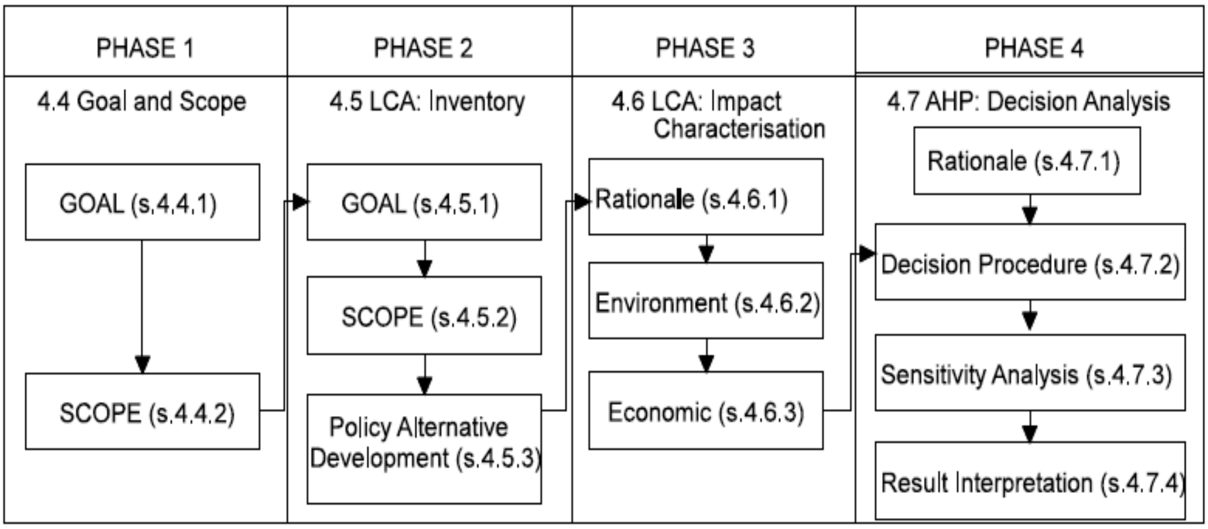


Figure 15: Decision Support Framework (Source: Framework designed by Author, 2015)

### 4.2.1 The Framework

The following discuss in detail the items being included in the decision support framework and what assumptions had to be made. The framework includes:

**Phase 1 – Goal and Scope**

This phase defines the objectives of the LCA. The expected outcome of LCA tool is stated and clarified. The scope of the research is, however, defined by limitations and impact classifications. The limitations define the notion of the designed framework. The impact classifications are then defined by seven criteria that will measure environment and economic aspect of recycling and reusing C&D waste.

**Phase 2 – LCA: Inventory Analysis**

The second phase of the research framework focused on Life Cycle Assessment with special focus on the inventory. A material flow chart model is considered within the system boundaries as set out in the scope of the LCA assessment. The LCA inventory covers the input and output and that impact outcomes are derived from the inventory data processed. The life cycle map is developed to explain the waste material flow from the system start to finish. With the life cycle map, a baseline scenario, which derived multiple waste management policy options/alternatives, is developed. Through this process, varieties of policy alternatives are assessed by the impact factor.

**Phase 3 – LCA: Impact Characterisation**

Following the collection of inventory data and the creation of the policy alternatives, then data is categories in relation to impact factor. In order to successfully complete phase 3, individual impact factor are categorised according to each criteria. The final outcome of the impact analysis are adopted by decision makers to bring the framework into a realistic and successful completion.

**Phase 4 – AHP: Decision Analysis**

Phase 4 completes the process by drawing upon the outcome generated and strengthened from the impact characterisation phase. The information obtained, through the process is used by decision makers in order to rationalise and review the outcomes of different policy alternatives. However, a sensitivity analysis is carried out and the outcomes are discussed appropriately.

### 4.2.1.1 Rationale

The decision-support framework is developed to help meet the research aims and objectives as well as to determine whether or not the null hypothesis: *“$H_0$: A decision-support model based on LCA and MCDA is not able to improve evaluation of economic and environmental benefits of recycling and reuse of C&D waste”*. It is therefore important to develop a system model that will enable observation of any potential effects of recycling, reusing and disposing of C&D waste.

## 4.3 Attributes to Decision Making Process

With the view to constructing a decision support framework, there is a need to understand features, characteristics and/or attributes to developing the framework. Achillas et al. (2013) identified four attributes one should expect to observe in a Decision Support System (DSS). The author’s list is very general and provides an even holistic perspective on the DSS principle. Achillas et al. (2013) specify that a decision support model must have a body of knowledge, a data or record-keeping capability that can present knowledge on consolidated basis in various customized ways, a capability for selecting a desired subset of stored knowledge for either presentation or for deriving new knowledge.

**Table 7: Characteristics of Decision Making System (DSS)**

| Authors | Attributes and Characteristics |
|---|---|
| **Alter 1980** | Decision support system (DSS) is designed specifically to facilitate decision processes<br>Should support rather than automate decision making |
| **Turban and Aronson (1995); Bani et al. (2009)** | Should be able to respond quickly to the changing needs of decision makers<br>Interactive, flexible and adaptable to support the solution of a non-structured management problem for improved decision making |
| **Zapatero et al. (1997; Power (2002);** | Facilitation, interaction, ancillary, iterated, task-oriented identifiable and decision impact<br>Performance data, flow rates, degree of replication, experimental control, environmental condition, degree of peer review |
| **Karmperis et al. (2013)** | Improves personal efficiency<br>Expedites problem solving (speed up the progress of problems solving in an organisation)<br>Generates new evidence in support of a decision<br>Reveals new approaches to thinking about the problem space |

Table 7 above shows the attributes of decision support system. For the purpose of the research key attributes include the input with regards to waste resources in relation to impact analysis of two key factors (i.e. economic and environmental) in relation to recycling and reusing C&D waste. These two key factors are designed to feed into decision procedures for the decision support framework, as should in Phase 3 and Phase 4. The use of MCDA and LCA has successfully helped to facilitate such attributes in order to justify the economic and environment benefit of recycling and reuse of C&D waste.

The attribute and characteristics of waste produced by waste generators is different and each of them has constraints. It is important to understand that solid waste is a complex, multidisciplinary problem involving economic and environment aspects, normative constraint about the minimum requirement for the recycling and sustainability issues. Solid waste management decision makers are challenged with a system that involves a variety of factors including financial costs, recycling rates, land use, labor needs, energy use, pollution generation, and equity in the number and demographics of people effected by a policy. In making decisions, the trade-offs among these factors remains the central concern. This leads to the development of a decision support model that will accommodate a large amount of data and information.

## 4.4 Phase 1 – The Goal and Scope

The goal and scope of the decision support framework are clarified on this section. As advised by the ISO 14040 (1997), the goal of LCA shall state application, rationale for conducting such study and the intended audience for the study. Phase 1 start by stating the goal and sought to address the scope of the framework. However, the scope of the framework defines three key elements (i.e. scope, impact characterisation, and limitations of the decision framework).

### 4.4.1 The Goal

The goal of the decision support framework is to aid decision making on policies relating to recycling and reuse of C&D waste. With this in mind, the framework will incorporate the two management tools of LCA and AHP (an aspect of MCDA model). Both LCA and AHP will be adopted to gather information on the C&D waste management and then use the information to develop a decision making process. The framework design is developed to enhance data interpretations for decision makers and possible areas of selecting policy alternatives on establishing the economic and environmental benefits of recycling and reusing C&D waste.

### 4.4.2 Scope

The scope of the framework covers key aspect of the two management tools (LCA and MCDA) where both tools are defined. This provides the rationale for suitability of location, limitations, and impact characterisation, which forms the backbone of the decision-support framework. The overall research scope is defined herein as well as impact characterisation to get a better understanding of the system.

#### 4.4.2.1 Research Scope

This framework limits its scope on two case studies (Global Construction Company (GCC) – Medium and Small-Scale Demolition and New Build projects) and key stakeholders. The decision support framework starts by identifying the prevalent fractions of C&D waste materials with the system. The C&D waste materials are then tracked from start to finish in order to record inputs and the outputs linked with the phases of C&D waste management. The framework continues to assess and identify the environmental and economic impacts for the different phases of waste system storage, collection, processing, recycling, reusing, and landfilling.

The framework will use six impact categories (carbon footprint, recycle and reuse rates, NPV, recycling and reuse values) that access the environment and economic impact. The research however assumed that there are other possible impacts (i.e. social and political impacts) that can be considered within the waste management systems. However, the impact criteria for LCA and AHP as well as the stakeholder involvement in decision-making are chosen so that they are both appropriate to complete and validate the decision-support framework. However, the criteria used are conformed using the reporting guidelines as postulated by Ulukan and Kop (2009).

#### 4.4.2.2 Identifying Key Stakeholders

Stakeholders serve as technical experts in what needs to be done and how it needs to be done. The effective management of C&D waste cannot be achieved without stakeholder involvement. Stakeholders are considered to be participants, and are used to validate the decision-support framework. The following stakeholders are considered in the case studies:

- Construction workers

- Project managers
- Contractors (waste specialists and local recyclers)

By identifying the stakeholders at an early stage of the research, the researcher was able to determine their requirements and expectations in terms of what they think will happen to them, their department, and the company as a whole as a result of the individual projects. Expectations tend to be much more ambiguous than stated requirements, or they may function as undefined requirements. They may be intentionally or unintentionally hidden. The researcher took account these possibilities, however, and considered what is needed for effective C&D waste management and alternative policy development.

#### 4.4.2.3 Role of Stakeholders in the Framework Development

A stakeholder is an individual who is affected by or who can affect a project's outcome. Stakeholders shape projects in the early stages, ensuring resources are available to contribute towards the success of a project, and provide insight regarding the probable reaction to a project's outcome, facilitating project adjustments when necessary to win organizational support (Nordmeyer, 2016). The roles of stakeholders change throughout a project's life cycle. The willingness of stakeholders to perform the activities assigned to them during the project planning process, however, greatly contributes to the success or failure of the project (Manowong, 2010; Somollo and Distura, 2014).

Management of any project in the modern world needs to be attuned to the cultural, organizational and social environment surrounding the project. It is crucial to understand such project environments fully and to assess the positions of relevant stakeholders, as well as their influences, in order to manage the planned projects or schemes successfully. Manowong (2010) points out that effective management of project stakeholders is an important part of the project's success. As such, stakeholders' acceptance of and satisfaction with management policy is vital. In terms of C&D waste management, it is necessary to identify and assess stakeholders' interests in and expectations of the prospective waste management scheme.

Stakeholders can form internal or external groups. Internal stakeholders are those formally connected to the project, while external stakeholders are those affected by the project (Gibson, 2000). In construction, internal stakeholders include project owners, clients, project leaders, designers, suppliers, and contractors. Meanwhile, external stakeholders are often regulators, public community groups, financing institutions, media, and consumers (Abdelhamid, 2014).

The stakeholders play a significant role in terms of LCA inventory data, impact categories, and the decision analysis process during the development of the framework. Stakeholders are considered operational role players in the management of C&D waste for the two case studies. Decision-makers are identified through stakeholder management, as stakeholders' attitudes and perceptions towards C&D waste management policy alternatives are examined. In addition, the decision analysis was designed around the key decision-makers and facilitated a consistent and effective decision-making framework.

Inputs (selected C&D waste) and outputs ($C0_2$ emissions) vary considerably depending on factors such as recycling, reuse, landfill techniques used, processing activities, distances between transfer stations, and C&D waste collections. Therefore, the framework uses average figures obtained from the case studies. Although there are limitations to the applicability of using average figures, this is consistent with the purpose of incorporating LCA at a generic, policy-focused level. The use of average data will identify the types and scales of impact categories likely to arise from C&D waste recovery and recycling target alternatives. Data in this thesis was sourced from the GCC's database, and analysis carried out using the sources discussed in the following section.

#### 4.4.2.4 Impact Characterisation

The impact characterisation adopted reflects the environmental and economic measures for policy options relating to managing C&D waste. The characterisation further represents the roadmap to meet the research aim and objectives as well as helping the researcher to align all identified criteria with the objectives. A few research studies support the use of management-oriented indicators as means of selecting the best options for waste management policies (Bani et al. (2009), Achillas et al. (2013) and Marzouk & Azab (2014).

Table 8 below shows the environmental impact measure. Within this category, decision makers consider Carbon Footprint and Recyclable Rate due to its simplicity and ease of use. This measure is commonly used to analyse environment criteria, which include acidification, eutrophic change, or waste use. In order to measure the duration of environmental measure in terms of Carbon Footprint, a 1-year period is considered. Carbon Footprint is the amount of carbon dioxide and other carbon compounds emitted due to the consumption of fossil fuels by a particular person, groups, object etc.

Table 8: Environmental Impact Criteria

| S/n | Name | Definition | Unit |
|---|---|---|---|
| 1 | Carbon Footprint | Measure of environmental impact of a particular individual or organisation's lifestyle or operation measured in units of carbon dioxide and also referred to as global warming potential GWP 100 | Kg of $CO_2$equiv |
| 2 | Recycled Rate | Amount of recyclable waste needs to recycle. Tam (2011) pointed out that the rate of recyclable waste can help generate income and create employment | % Waste recycled |
| 3 | Reuse Rate | Amount of reusable waste needs to be reused or reclaimed | % Waste reused |

According to Wieldmann (2007) Carbon Footprint is a measure of environmental impact of a particular individual or organisation's lifestyle or operation measured in units of carbon dioxide and also referred to as global warming potential GWP 100. The time duration considered for GWP 100 in terms of the impact greenhouse gas is 100 years and measured in "*Kg. of CO2equiv.*" exposed into the atmosphere for a year. The UK emissions are measures in "KgCO2e" (See Appendix 3 for carbon calculation parameters).

Baumann and Tillmann (2009) noted that the extent of environment impact considers Kyoto Protocol's six greenhouse gases: Hydrofluorocarbons (HFCs), Carbon Dioxide, Methane, Perfluorocarbons, Nitrous oxide, and sulphur hexafluoride (SF6). Different activities emit different gases, for example, burning fossil fuels releases carbon dioxide, methane, and nitrous oxide into the atmosphere. The Kyoto Protocol (1997) is an international treaty, which extends the 1992 United Nations Framework Convention on Climate (UNFCCC) that commits State parties to reduce greenhouse gases emissions, based on the premise that (1) global warming exists and (2) man-made $C0_2$ emissions caused it (Grub, 2004; Gupta et al., 2007).

The recycle and reuse rate of the system is a functioning measure. It explains the rate of recycling and reusing of C&D waste within a given year for the waste system. The purpose of determining the rate of recyclable and reusable waste material is to show clarity in functional requirements for the system. It determines any ineptitude found in process or storage. However, rate of recyclable and reusable of waste material also considers non-organic materials such as glass, plastics etc. found in the waste system. Thus, organic waste materials such as food and other items are omitted from the waste system.

An economic assessment is required of the two case studies and this must form a private cost savings potential. Table 9 shows the economic impact criteria as assumes that most policies relating to waste management are controlled by budget and cost saving intensions. However the goal of the economic review is to complete that function and assess the cost-saving decisions considered by the two case studies. Significantly, the Life Cycle Costing (LCC) is considered by incorporating the Net Present Value (NPV) of the waste system. This supports the full documentation of all income and spending. Thus, estimations consider the use of value of cost risk and that of inflation respectively.

**Table 9: Economic Impact Criteria**

| S/N | Name | Definition | Unit |
|---|---|---|---|
| 4 | Net Present Value | The functional value of a policy alternative. NPV referred to all monetary in terms of income and spending. | GBP (£) |
| 5 | Recycling Value | The value of recycled waste material generated by case study 1 and 2. All recyclable waste within the system is considered and estimated. | GBP (£) |
| 6 | Reuse Value | The value of reused waste material reclaimed by case study 1 & 2 | GBP (£) |
| 7 | Job Creation Potential | The current and potential future job creation that can be developed or lost as a direct outcome of waste management system | Persons |

Table 9 above shows the list of economic and social impact criteria, which represents a link to economic viability that can be adopted to evaluate different policy alternatives, as adopted by Ulukan and Kop (2009). However, the recycling and reuse value that be obtained from the system can see as 'secondary materials' with high market value and readily available for local contractors for sale. Finally the issue of job creation brings back the emphasis on *"benefits"* of recycling and reuses operation. This also relates to the social functions of various processes as well as the opportunities within the system.

#### 4.4.2.5 System Limitations

The system’s limitations are considered and analysed for the C&D waste system. The current limitations for the framework include:

- Operations within the Case study 1& 2 involving waste system handling.
- Contractors and City of London waste handling for the two case studies.
- Only wastes developed within the identified system for case study 1 and 2 were studied.

No attention will be placed on input and output of waste system unless it has direct course on the key factors such as recycling, collection, storage, processing, transport, and landfilling. The system for the framework considers five stages for the waste life cycle as adapted after Baumann and Tillman (2009), Vosseberg (2012), De Beer (2013). The five stages are considered from start to finish as it also runs through an intermediate interphase and then proceeds to the finish phase as show in Figure 16.

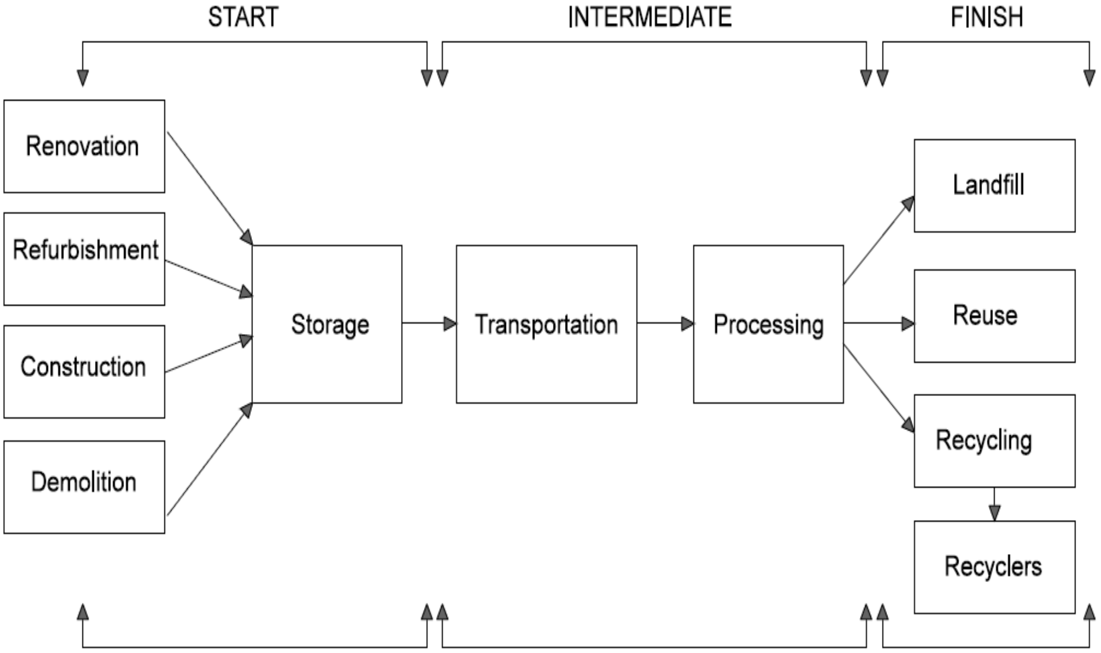


**Figure 16: The phases and limitations of waste life cycle (Source: Life cycle flow designed by Author, 2015)**

## 4.5 Phase 2 - LCA: Inventory

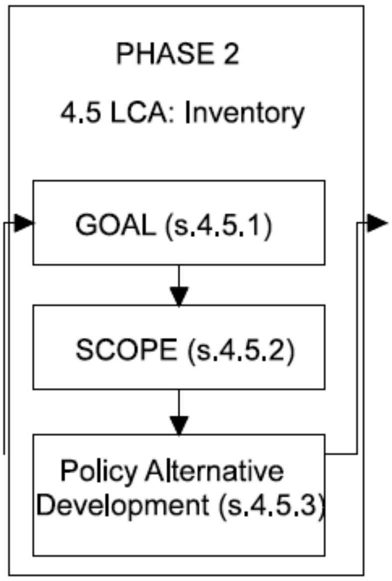


Figure 17: Stage 2 of the decision support framework

The stage 2 of the decision support framework covers the inventory analysis, which covers the Life cycle map, waste system input and output as well as the policy alternative development. Inventory data is important to the aspect of impact assessment as discussed earlier. Thus, this consists of two parts: data capture (input/out) and the life cycle map. A full documentation of the input/out data will be presented. Conversely, the life cycle map will be divided into two parts categories (environment and economic impacts) and they are tracked throughout the waste system flow.

### 4.5.1 Life Cycle Map

The Life Cycle Map (LCM) is designed to give direction to the inventory analysis. The life cycle map outlines limitations, resources, and waste handling and material flows. According to Vosseberg (2012), life cycle map is a complex process and can be perceived as iterative and it functions as characteristics of waste system discussed in terms of input and output system. Following illustration in figure, the life cycle map consists of six-stage process (i.e. storage, transport, processing disposal, reuse, and recycle) within the waste management process.

Both inputs and outputs relating to environment and economic impacts are evaluated within the waste categories. The process will be studied thoroughly in order to investigate how one process after the other in terms of impact characterisation (i.e. impact regarding key factors such as operations, fuel cost, greenhouse gasses etc.).

#### 4.5.1.1 Rationale

The development of LCM is considered to be the backbone of the Waste Management System (WMS). By designing a life cycle mapping, the researcher was able to determine expected system boundaries, resource material estimation, waste handling activities and stakeholders' involvement, requirement and expectations. It is therefore important to concurrently record all inputs and outputs during the study to enable observation of any potential impact on effective management of C&D waste.

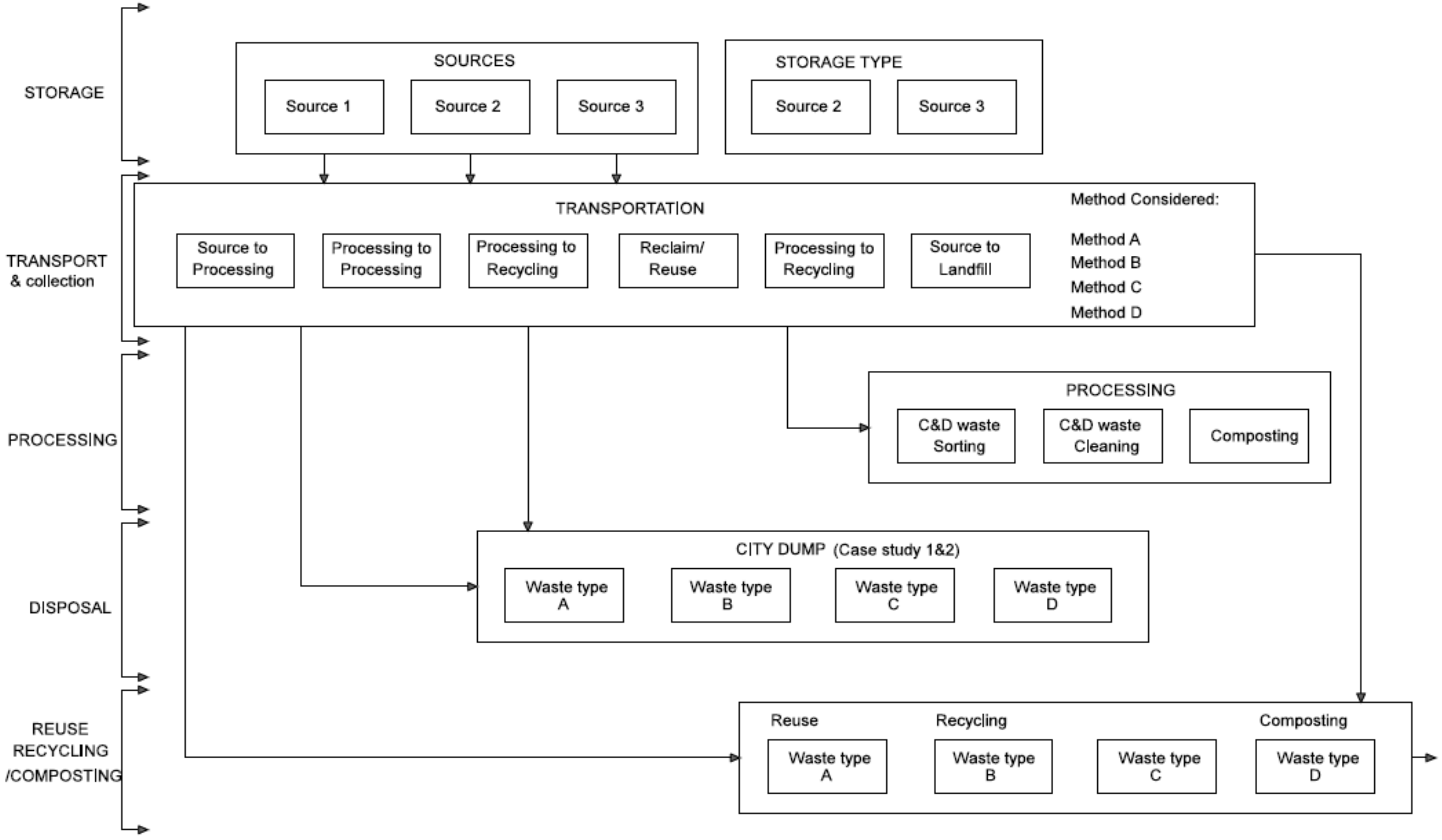


Figure 18: The life cycle map considered for evaluating the waste flow within the Case study 1&2 (Source: Designed by Author, 2015)

Figure 18 illustrate the life cycle map, which is created according to the six stages (i.e. storage, collection, transport, processing, disposal, reuse and recycling) highlighted in Figure 16. Within the stages, inputs and outputs relating to environmental and economic impact are observed within the waste system flow. The life cycle map shows the measure for both economic and environmental impact using parameters such as cost inventory (such as operations, fuel cost, and greenhouse gasses).

### Stage 1 - Storage

Storage covers how and where C&D waste is stored and shown as the initial step of the waste management system. Three sources (i.e. waste from Construction, Demolition and Renovation works) will be noted and are assumed to cover the two case studies identified in Chapter 5. Main source of waste stream for the system covers commercial, residential, and manufacturing facilities respectively.

### Stage 2 - Transport

Stage 2 covers the transportation for collection of recyclable and reclaimed waste materials for material reuse.  This is, however, transported through various volumes and sizes of trucks to designated base for either processing for recycling and reuse of building waste or for disposal to landfill. The inventory analysis will attempt to investigate the average travel distance between locations and measured to a year. However the type of transportation are investigated and documented along with varying fuel and haulage efficiencies. The current study assumed only one fuel efficiency, with a thorough investigation of distance per trip both to processing centres and to waste material processing base.

### Stage 3 – Processing

As shown in Figure 18, the processing stage covers the C&D waste sorting operations, C&D waste cleaning and composting. One can see in Figure 16 that the processing part is categorised under the intermediate phase of waste life cycle with the aim to address the issues with separation of C&D waste stream.

### Stage 4 – Disposal to Landfill

At the finish phase of the waste life cycle as illustrated in Figure 16, a decision to reuse, recycle or to divert C&D waste to landfill will be made. However, the system will be tracked throughout the processing times to determine the finish stage for waste types. Landfilling is considered as a last resort to managing C&D waste; however it is used to consider environmental and economic impact of such action. Landfill actions will be considered for the two case studies.

**Stage 5 – Reuse and Recycling**

Both waste reuse and recycling operating is considered to have positive impact on the environment and financial aspect. The role of reuse, however, is all too overshadowed in many municipal organisations by recycling, and this is clearly reflected in current policy and legislation. While recycling is indeed key to sustainable resource management, it is a risk to neglect enhancing the conditions for reuse activity to flourish (Addis and Schouten, 2004).

### 4.5.2 Input and Output Data

Following stage 2 of the design support framework, the key data requirements are stated and evaluated. The data is identified in the waste flow diagram as shown in Figure 15 from start to finish. The types of data identified in the waste systems are: waste stream survey, economic survey, and the life cycle process data. Thus, the collection of waste system data provides the opportunity to successfully measure environmental and economic impacts of recycling and reuse of C&D waste.

#### 4.5.2.1 Waste Stream Survey

There is a need for a standard waste data in order to achieve a precise economic and environmental impact estimate. Data requirements in this sense cover weight and types of waste generated by the two case studies. The purpose of this survey is to identify quantities and waste composition generated by the two case studies. However, the survey focused on all forms of C&D waste that can be recycled and reused. Following the data collection process, impact categories are determined for different waste types. Continuous tracking of waste data will be employed and samples will be re-evaluated following an iterated process. The collection of waste data involved 15 categories, which is weighted individually following a structured timeline.

#### 4.5.2.2 Economic Survey

The economic survey covers that Life Cycle Costing (LCC) which eventually led to cost analysis of waste management. The revenue and costs related to transportation, collection, landfill fees, and operation costs of processing and disposal. The use of the LCC tool helps in the estimation of economic impacts and contributions from the waste life cycle. LLC is investigated on each stage of the waste life cycle and within its scope and limitations.

Cost associated to reuse and recycling of building waste are considered in terms of transportation, processing and fees associated to diversion to landfill. However, additional costs overhead are allocated to each waste stream. The data collected is directly from secondary source such as waste management budgetary report obtained from Case study 1 and 2.

#### 4.5.2.3 Life Cycle Process Data

Data relating to life cycle process is expected to provide a detail analysis of the waste management system. The waste life cycle consists of a process data with the following attributes: size of system in relation to population and service provided, process clarity in terms of start to finish, limitations that exist within the current system. Thus, data gathered from primary source for the research includes a qualitative approach by carrying out a face-to-face interview with managers or recyclers within the waste management system. Most data source includes that secondary source, by reviewing and analysing reuse and recycling reports for the two case studies.

### 4.5.3 Policy Alternative Development

The outcome of the fully analysed life cycle inventory directly leads to the development of different policy alternatives. The policies are stretched from the current waste management system to integrate different prospects within the current scenario. Alternatives are defined by the completeness of the 3Rs principle of waste management hierarchy:

- Reduce and Reuse - Level 1 (favoured option)
- Recycling or Composting – Level 2 (favoured option)
- Landfill (Disposal) –Level 3 (less favoured option)

Alternatives and/or options increasingly attempt to be decrease a significant percentage or waste and be more recycle-oriented. Thus, Figure 18 provides a valid example of alternatives based on performance according to waste minimisation hierarchy relying on the 3Rs principle.

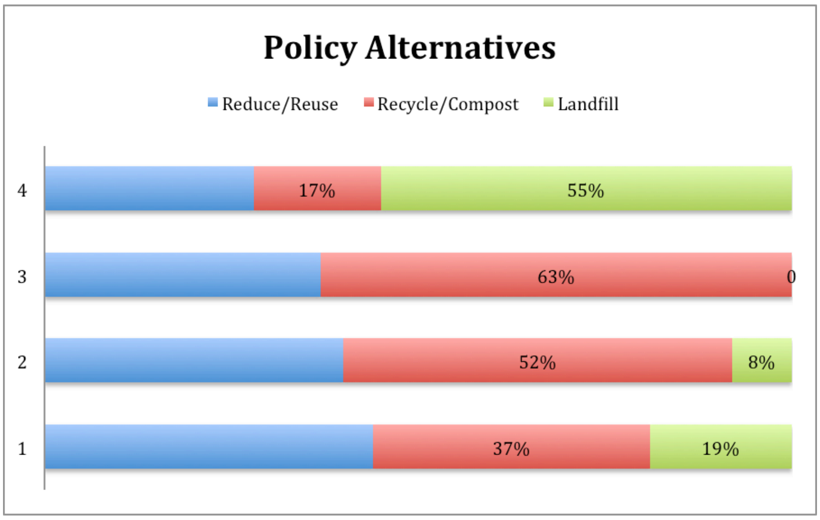


Figure 19: Example of how different alternatives are developed using % allocation (Source: Data compiled by Author, 2015)

For alternative 1, about 44% waste was reduced or reused, about 37% waste was sent to recycling facilities and the remaining 19% was diverted to landfill. Alternative 2 shows that 40% reduction in volume of waste from alternative, 52% of waste within the system is sent to recycling and about 8% diverted to landfill for disposal. Alternative 3 shows 37% reduction in volume of waste from alternative, 63% waste diverted to recycling operation, 0%was sent to landfill.  Finally, alternative 4 indicates 28% reduction in waste in system, 17% waste was diverted to recycling facilities, and a relatively high amount about 55% was sent to landfill.

## 4.6 Phase 3 - LCA: Impact Characterization

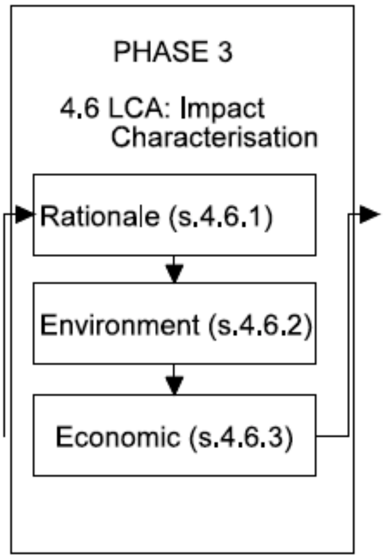


Figure 20: Phase 3 of decision-support framework

The alternatives developed after the inventory analysis in Phase 2, which requires an evaluation based on their impact characteristics. Within this context, both environment and economic impacts are investigated and evaluated. Thus, the process of reviewing the six stages of waste system provides decision makers the opportunity to easily assess information within the waste system.

### 4.6.1 Rationale

The impact characteristics cover the measure of environmental and economic impact for the waste input data with the help of six criteria. The processes successfully include the arrangement of steps within a LCA model. The impact measures are translated into a simplified format at the completed stage of the framework to support an effective decision support process.

### 4.6.2 Environment Impacts

Following the discussion on environment impacts three elements (carbon footprint, recycle rate and reuse rate) are considered. This aspect of the decision support framework are thoroughly evaluated and analysed in terms of impact categories. Figure 21 shows the environmental impact categories selected in terms of the inventory data of life cycle within the waste management system.

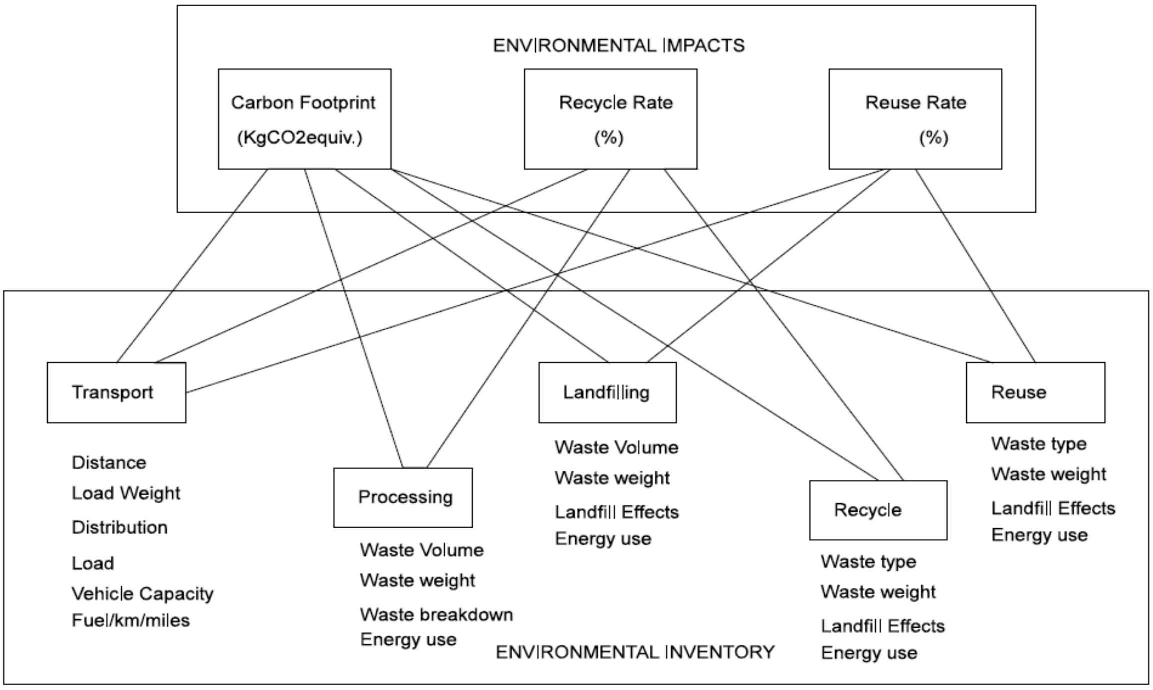


**Figure 21: Environmental impact category selected in relation to inventory data of waste management life cycle (Source: Designed by Author, 2015)**

#### 4.6.2.1 Carbon Footprint

As described earlier in Table 8 (i.e. Environmental criteria), Carbon Footprint is the first environmental indicator or relating to the measure of greenhouse gas emissions that occur across the waste management life cycle. Figure 21 illustrates data expected from environmental inventory within the waste management system (WMS). With this in mind, one can simply assume that transport distance has great influence on the amount of fuel required (i.e. the higher the fuel required the higher the Carbon Footprint.

The outcome of the environmental inventory for all waste categories defines in the scope of the research. However, Carbon Footprint is shown as the global warming potential (GWP) measured over 100 years for "*kg of CO2equiv.*" (Wieldmann, 2007; Defra, 2009). The carbon footprint helps many project managers and recyclers to measure the total amount of greenhouse gas emissions from different waste management options. NEF's SCC tool was used to calculate Carbon footprint and a brief history of this tool is provided in Appendix 9.

SCC tool uses conversion factors in order to provide 'Kg*CO2e'* of different waste types and the methods involved in processing. A practical example of the *Carbon Footprint calculation* is diverting 2.8kg plasterboard to landfill results in 1.3 Kg$CO_2e$ being released. The same amount of plasterboard was diverted to recycling; about -2 Kg$CO_2e$ would be released or avoided. From Figure 21, the second and third indicators "Recycle and Reuse Rate" was provided and used for environmental impact measure. These two rates were selected due to the activities within the waste management system.

The rates are considered as the measure of the extent of recycling and reusing of building waste within the system in relation to a known policy alternative. The key indicators are accumulated from the total waste that is recycled, reused, and/or sent to landfill. However, the impact is dependent upon the mass of waste and the adeptness of processing and storage facilities. The rate is determined as a percentage of waste sent recycling facilities, and that reused as reclaimed materials to the waste diverted to landfill.

### 4.6.2.2 Estimating the Recycle and Reuse Rate

Reusing and Recycling are recognised today around the world as a construction and demolition waste management strategy to prevent huge tipping fees due to the scarcity of landfill sites. The idea of ‘reuse’ and ‘recycle’ of many construction materials is a smart decision for all builders, whether they are interested in environmentally friendly building or not. However, the direct reuse of construction and demolition waste in its original and/or slightly improved involves reprocessing of used materials into secondary of new materials.

Equation formulated for the rate of reuse and recycling of C&D waste is:

**Equation 1: Rate of reuse and recycling C&D waste**

$$(DRR) = ASM/TW \qquad (1)$$

*Where:*

***DRR*** *is the Rate of reuse and recycling Construction and Demolition waste (%)*

***ASM*** *is the Actual Secondary Material (i.e. Reusable and Recyclable waste) (Tonnes per month)*

***TW*** *is the Total Waste (Tonnes per month)*

The degree of creating secondary materials (i.e. reusable and recyclable waste) shows that waste management practices involving reusing and recycling construction waste in relation to the two case studies. Within this context, ‘1’ shows fully development of secondary materials whilst ‘0’ shows that all waste is to be transferred to disposal. The rate of reuse and recycling of waste will be applied to the case study by considering total estimate of individual waste composition

### 4.6.3 Economic Impacts

The economic impacts seek to show clarity on overall operational costs of running waste management system. Figure 22 shows the association between expected financial inventory data and their respective impacts on the selected impact characterisation in stage 3. Also, Figure 22 shows the indicators for the economic impact measure. The first indicator is the NPV for economic and/or cost performance of the waste management system in relation to various life cycle phases. The economic impacts assessments are to complete that function and assess the cost-saving decisions considered by the case study. However, this measure strictly relates to the two identified case studies and does not cover any cost or monetary transactions for other cases.

### 4.6.3.1 NPV

The NPV considers all expenses and income that is generated from the system within a year period. Thus, an extension of NPV's estimate is considered for various alternatives over five-year period. Significantly an annual cost intensification being 10% is adopted and was derived from the average rise in city waste tariff system. The cost intensification considers the increase in associated costs for different systems such as higher fuel or fees/charges relating to landfilling with an additional increase by service providers. Conversely, the discount rate is estimated at 3.5% (UK public service discount rate), considering the current (as of August, 2015) prime bank lending interest rate of 1.5% and estimated for risk and inflation at 2.5% (Bank of England, 2015). Figure 16 below shows the impact categories in relation to economic inventory data obtained from the waste management life cycle.

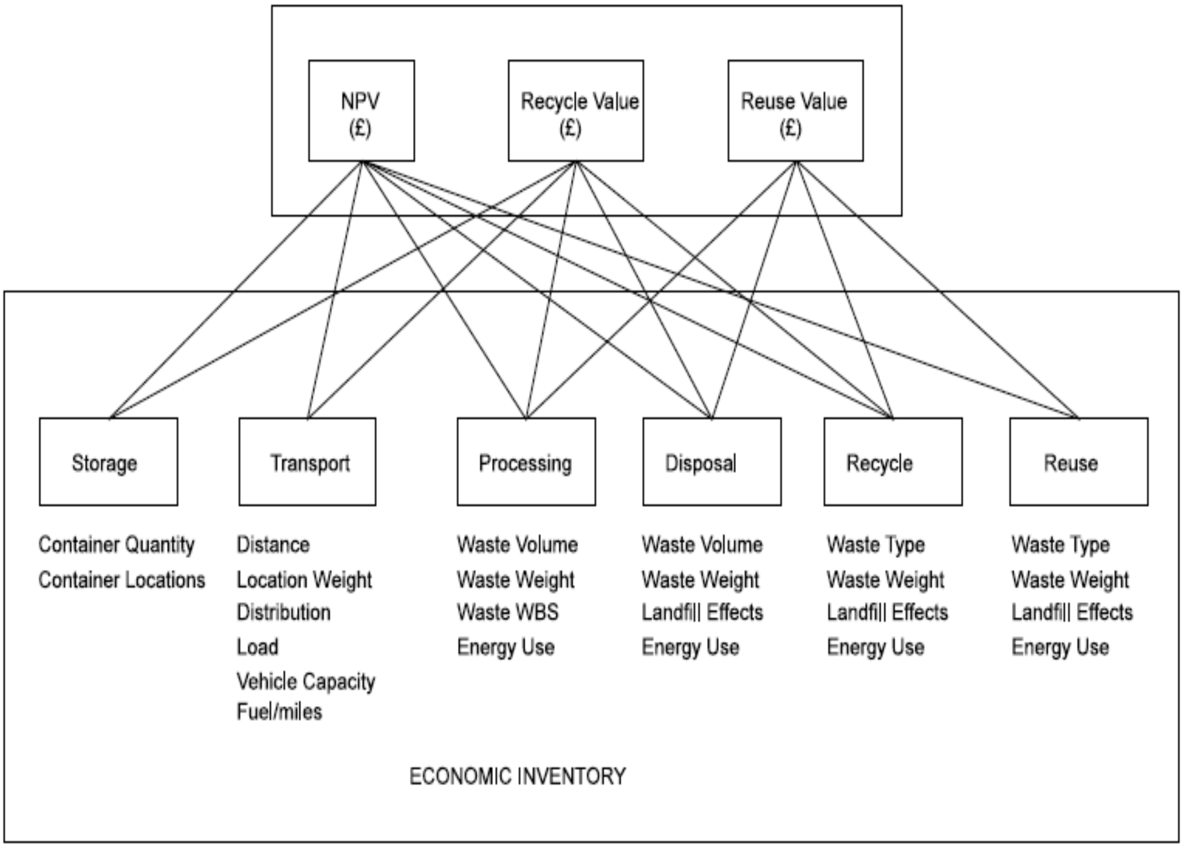


Figure 22: Economic impact category selected in relation to the inventory data of waste management system life cycle (Source: Designed by Author, 2015)

#### 4.6.3.2 Recycle and Reuse Value

Practical example is economic impact is the collection of waste during sorting using containers. The amount of containers that are collected by the city (from individual case study) correlates to potential customer's benefits. At every stage during sorting and handling, C&D waste should be processed to optimise material recovery and diversion from landfill (Liu and Wang, 2013). Cost savings are realized when the avoided cost of disposal, reductions in needed solid waste services and potential revenue from the sale of recyclables are factored into the overall equation (Damuth, 2010).

The economic feasibility of a recycling program often depends on whether the added cost (time, effort and resources/equipment) associated with the recycling activities is less than the avoided costs (tipping fees, labour, haulage, maintenance, taxes, and local permanent fees) (Duran et al., 2006; Begum and Siwar, 2006; Srour et al., 2012; Calvo et al., 2014). Nisbet et al. (2002) pointed out that the economics of reuse and recycle of C&D waste lies with the capital investment in equipment to produce secondary material. The reuse and recycling value of the waste diverted to landfill are calculated using the waste-pricing index, which are included in Appendix 3 and 5.

### 4.6.4 Other Related Impacts

Other related impact, which is considered away from the decision framework, is the social aspect in terms of jobs creation.  It is important the actions of recycling and reusing of building waste boost the overall employment in the city of London. The end result of recycling operations often leads to the social benefits where employment opportunities are seen through collection and transportation of waste composition, as well as people being employed to engage with waste sorting, cleaning and collecting and finally people are employed to help transport minimal amount of C&D waste to landfill. The study will discuss this aspect further on the analysis and discussion section based on the outcome of the environmental and economic impacts.

## 4.7 Phase 4 - AHP: Decision Analysis

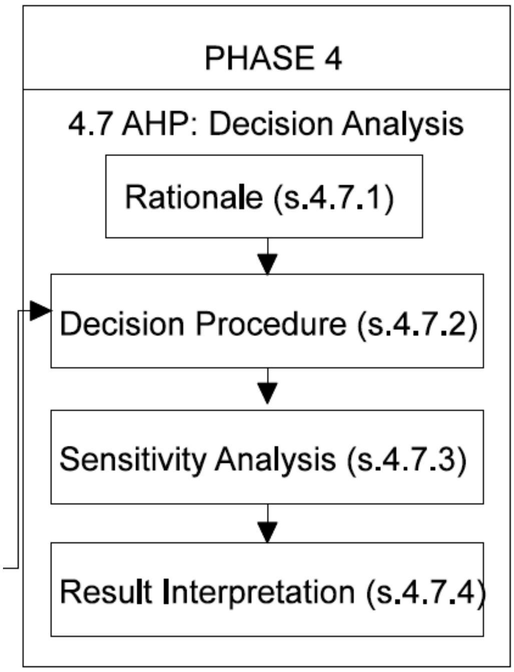


Figure 23: Phase 4 of the decision support framework

Phase 4 of the decision-support framework as shown in Figure 23 adopts the guidelines described in Table 6. First, Phase 4 of the decision-support framework identifies the stakeholders and assesses their significant role in the framework development (i.e. subsection 4.4.2.2 and 4.4.2.3) and this meets the first and second guidelines outlined in Table 6. By identifying the role of stakeholders in developing the decision-support framework, the researcher was able to consider the cognitive nature of decision makers in responding to the research objectives.

Second, Phase 4 was able to use the guidelines in Table 6 to determine key issues with decision-making in relation to policy alternatives (i.e. decision makers was able to rank individual policy alternatives using weighting system developed in pairwise comparison aspect of the AHP model). Third, the Multi-criterion aggregation (MCAP) procedure have been incorporated by selecting scoring the policy alternatives on the criteria and checking the consistency of scores in each criterion. This method supports a study carried out by Dodgson et al. (2009) and outlined in Table 4 (application of MCDA's step).

Phase 4 adopts the decision procedure section to meet the Ulukan and Kop's (2009) guidelines. However, the application of MCDA's steps considers the combination of weights and scores for each policy alternative against the criteria. An estimate of overall weights and score at each level in the AHP hierarchy were carried out and illustrated in Figure 24.

Equation (4) and (5) shows the calculation for decision maker's confidence and consistency in policy alternative preference. This equation is used to estimate for the consistency level of decision-making in relation to policy alternative comparisons. This aspect meets the fifth item on the guidelines outline in Table 6.

Finally, results are examined as well as the sensitivity analysis was carried out to justify the viability of key choices that impact the ranking of individual policy alternatives. MCDA steps are employed throughout the Phase 4 with the support of the guidelines outlined in Table 6. Rationale was discussed for the framework development is further discussed below. Based on the background study of MCDA tool, AHP was carefully selected for the purpose of the study.

### 4.7.2 Rationale

However, the tool was chosen to allow for inputs from multiple decision makers as well as to arrange tangible and intangible factors in a systematic manner to arrive at a feasible solution. The Analytic Hierarchy Process (AHP) is an interesting tool often used to convert assessments, which are relatively subjective, and give them overall scores and weights. This tool breaks down complex multi-criteria issues into a system of hierarchies and subsequently ranked.

AHP model requires the following to proceed: develop a performance matrix, obtain weights for each object of each level, check consistency and rank each available alternative (Saaty, 2008). The following steps of AHP are considered as adapted after Saaty (2008):

- Define the problem and determine the kind of knowledge sought.
- Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a holistic perspective through the intermediate levels.
- Construct a set of pairwise comparison matrices. Thus, each element in an upper level is used to compare the elements in the level immediately below with respect to it.
- Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Continue doing this for every element and then for each element in the level below add it weighted values and obtain its overall or priority.

Figure 24 below shows the classification of matrix as stated by decision makers and an LCA impact matrix originally established via LCA model. The two model and integrated and a policy ranking system is developed accordingly. Thus the ranking system aid decision making process to promote consistency and accountability.

### 4.7.2 Decision Procedure

The decision makers consistently facilitate the decision procedure based on the impact measurement as stipulated in the LCA model. Other contributing factors such as experience and views on policy alternatives are considered. Figure 24 shows the development of decision hierarchy framework, which is split, into four key levels resulting to a three-step process otherwise known as pairwise comparison. The decision design phases (1-3) considered are illustrated in Figure 24 below and discussed in the following pages.

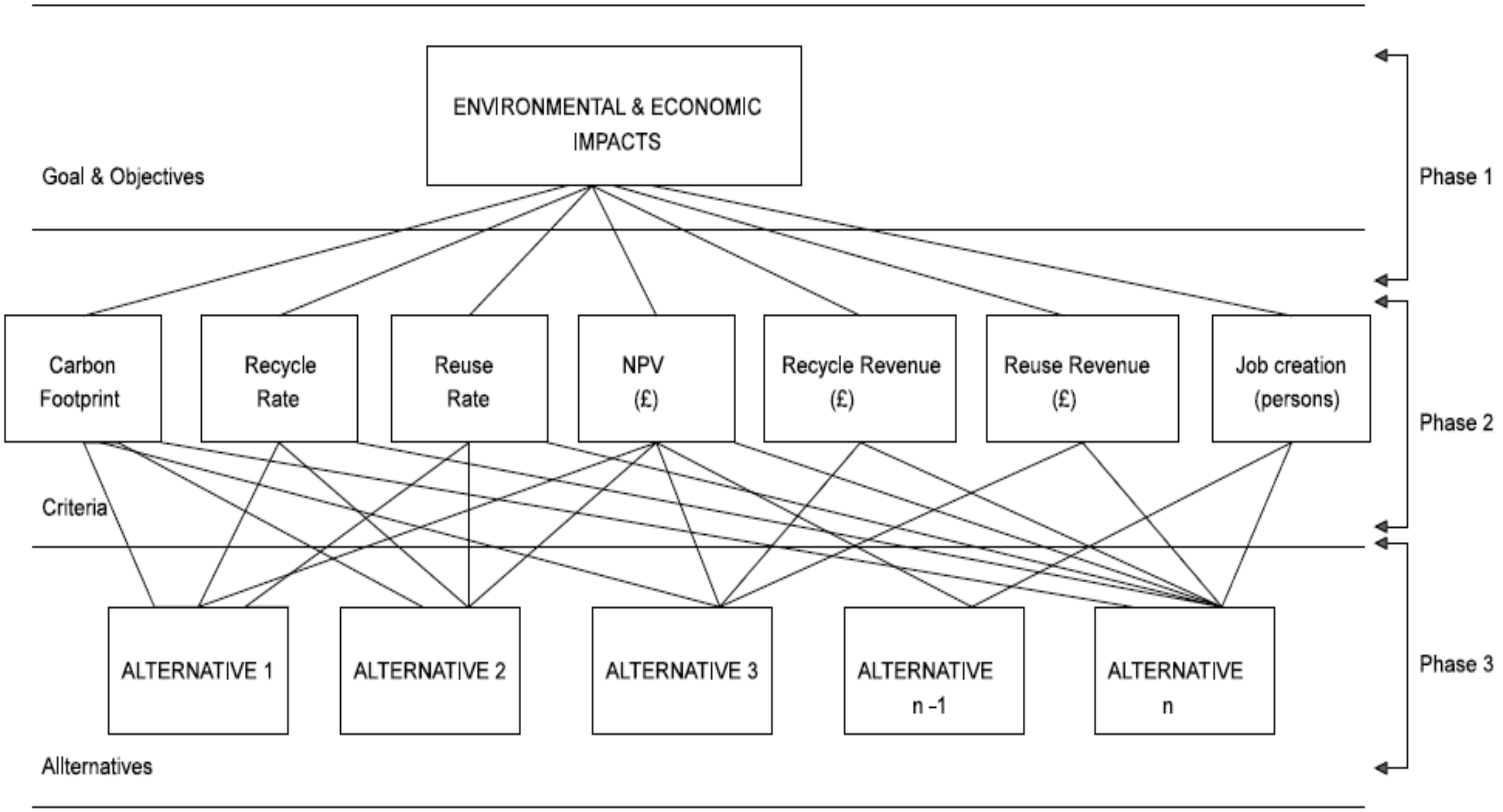


Figure 24: AHP application to LCA model and other decision preferences (Source: Designed by Author, 2015)

Phase 1 consists of main goal of the study, which is the environment and economic goals; other related research goal is that of the job creation, which the output of the initial goal set is. Phase 2 sets out seven criteria, which are weighted against the main goal (environmental and economic measure). Thus, each criterion is only weighted against its respective objective, for Carbon Footprint is only weighted against environmental benefits.

Phase 3 provided each alternative, which is compared to every criterion. This is performed is an amalgamated impact support. Decision makers sought to make comparisons on an analogous estimating (expert judging). However, decision makers can express their views on preferences based on a robust impact measure using pairwise comparisons.

#### 4.7.2.1 Relationship between Phases (AHP Model)

In developing the AHP model as shown in Figure 24, key issues are decomposed into a hierarchy of criteria and policy alternatives. There is a strong relationship between the three phases shown in the AHP model. Phase 1 is linked with Phase 2 and this further linked with Phase 3. The main problem (main concern on managing C&D waste) is the environmental and economic impacts illustrated in Phase 1. The objective of the research work helps the researcher to define the overall criteria considered to design the decision-support framework, which has led to the policy alternatives in managing C&D waste.

According to Triantaphyllou and Mann (1995) the AHP has attracted the interest of many researchers mainly due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain. The AHP model can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, subcriteria, and alternatives (Saaty, 2008). Using a set of pairwise comparisons derives the pertinent data. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. If the comparisons are not perfectly consistent, then it provides a mechanism for improving decision consistency.

An important part of the AHP process is to accomplish three steps (i.e. state the objectives, define the criteria, pick the alternatives). This information is then arranged in a hierarchical three as shown in Figure 24. Phase 1 is further decomposed into Phase 2, which further outlines the criterion 1 to 7 (criterion 7 was ignored due to the scope of the research). Criterion 1- 6 is considered on application of the decision-support framework for the case study review). The relationship between the three phases under the AHP model shows that importance of ‘rethinking a process’, another way of decision-making and/or a need for a new approach to managing C&D waste.

Phase 2 is then decomposed into Phase 3, providing policy alternatives (decision maker’s preference for effective management of C&D waste). The information provided through ‘*criteria and objectives’* are then synthesized to determine relative rankings of alternatives. However, both qualitative and quantitative criteria can be compared using informed judgements to derive weights and priorities. Pairwise comparisons are considered as the relative importance of one criterion over another can be justified (see subsection 4.7.2.3).

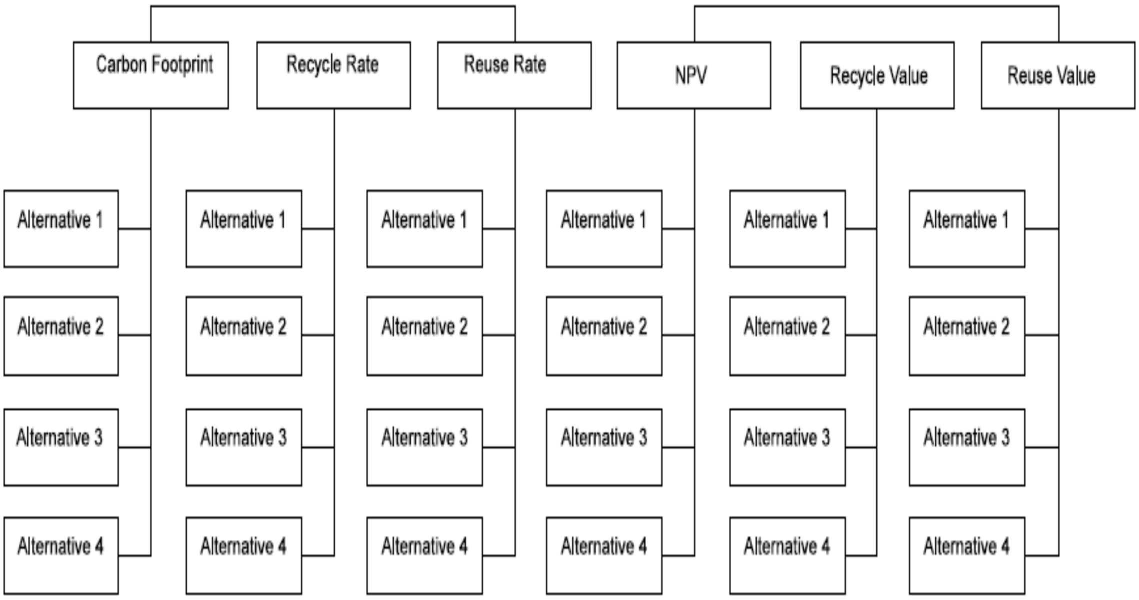


Figure 25: Matching criterion with alternatives

Examples of policy alternatives are: reduce/reuse, recycle/compost, and landfill. Individual policy alternatives are ranked and scored using ‘percentage (%)’ to demonstrate decision maker’s preference.

### 4.7.2.2 Amalgamated Impact Support

The amalgamation of results is required to assemble all elements of the life cycle as a cohesive whole. A support system will be considered in step 3 as shown in Table 10. The reason behind this approach is to enable decision makers to observe how different policies relating to alternatives influences seven environmental and economic impact criteria of the waste life cycle.  A practical example of Carbon Foot print support system is illustrated in

Figure 25. Thus, individual criteria have its own unique support system with data developed with an underlying five elements.

Table 10: Amalgamated Impact Support (Source: Designed by Author, 2015)

| Elements | Description |
|---|---|
| 1 | Describes an overview of results of the LCA in relation to Carbon Footprint |
| 2 | Gives a summary of the outcomes of the policy alternatives presented. The policy alternatives are manually developed, in relation to the impact results |
| 3 | Gives the weighted guide. Various policy alternatives that are kept on the sheet in order to keep decision makers fully aware of the policy implication |
| 4 | Provides definitions to Decision makers individual steps that have been weighted items |
| 5 | Provide two data: Consistency Ratio (CR) and a ranking system for different alternatives. The first information aid the process of communication as user is fully aware of the comparisons and decision made. |

### 4.7.2.3 Development of Pairwise Comparisons in AHP

To make comparisons, we need a scale of numbers that shows how many times more important or dominant one element is over another element with respect to the criterion with respect to which they are compared. Preferences and consistency is essential for all decision makers within the designed framework. The pairwise procedure is adopted to develop ranking of different policy alternatives considered by decision makers. Pairwise remains an important tool for all three steps of the AHP with the consistency and ranking system. Table 11 exhibits the scale of numbers. Figure 24 shows an example in which the scale is used to compare the relative waste management system.

Table 11: Scale of absolute numbers indicating interpretations of entries in pairwise comparison matrix (Adapter after Saaty, 2008)

| Intensity of Importance | Interpretation | Explanation |
|---|---|---|
| 1 | Equal importance (objective I and j) | Two activities contribute equally to the objective |
| 2 | Weak or slight | Experience and judgement slightly favour one activity over another |
| 3 | Moderate importance (objective I and j) | Experience and judgement slightly favour one activity over another |
| 4 | Moderate plus | n/a |
| 5 | Strong importance | Experience and judgement strongly favour one (I) activity over another (j) |
| 6 | Strong plus | n/a |
| 7 | Very strong or demonstrated importance | Activity is favoured very strongly over another; its dominance shown in practice |
| 8 | Very, Very Strong | n/a |
| 9 | Extreme importance | The evidence favouring one activity over another (i.e. objective I is absolutely more important than objective j) |
| Reciprocal of above | If activity I has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with I | n/a |
| 1.1 - 1.9 | If the activities are very close | May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities |

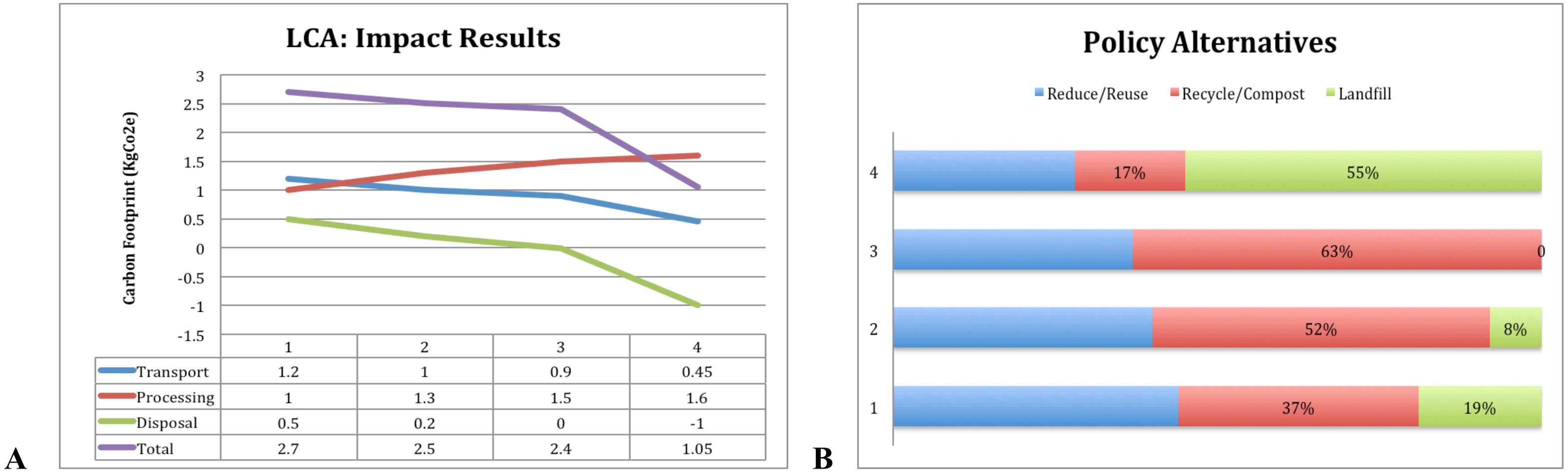


Figure 26: Amalgamated Example

## PAIRWISE COMPARISONS

Table 12: Scale of absolute numbers is used for pairwise comparisons

| Policy Alternatives | Percentages |
|---|---|
| 1 | 44% |
| 2 | 40% |
| 3 | 37% |
| 4 | 28% |

C

Suppose there are *n* objectives that are being adopted, where n is the number of criteria. A pairwise comparison matrix (A) is used, which expressed that *n* x *n* matrix. The matrix encourages entry in row i and column j of A (i.e, aij showing how much more important objective i is than j) the extent of importance is measured by an integer scale from 1-9 as shown on table 10. It is assumed that for all I, it is essential that aii = 1. Thus, if aij = k, then consistency will be aji = i/k. In case of n objectives, let wi = the weight given to objective i. in AHP model, weight (wi) is determined with an assumption that decision maker is perfectly consistent. Therefore, matrix A forms an equation (2) in this regard. Where w = $[w_1\ w_2\ \ldots.\ w_n]$ from A, using equation 2.

**Equation 2: Pairwise comparison matrix (A)**

$$A = \begin{bmatrix} \frac{w1}{w1} & \frac{w1}{w2} & \cdots & \frac{wn}{wn} \\ \frac{w2}{w1} & \frac{w2}{w2} & \cdots & \frac{w2}{wn} \\ \vdots & \vdots & & \vdots \\ \frac{w1}{w1} & \frac{w1}{w2} & \cdots & \frac{wn}{wn} \end{bmatrix} \tag{2}$$

**Table 13: Random index (RI) Value**

| n | RI |
|---|---|
| 2 | 0.00 |
| 3 | 0.58 |
| 4 | 0.9 |
| 5 | 1.12 |
| 6 | 1.24 |
| 7 | 1.32 |
| 8 | 1.41 |
| 9 | 1.45 |
| 10 | 1.51 |

Where w = [wi $w_2$ …. wn] from A,

**Equation 3: Pairwise comparison weight - a non-dimensional vector**

$$Aw^T = Xw^T \tag{3}$$

X in eq. (3) is an unknown number, whilst $\mathbf{w}^T$ is an unknown n-dimensional column vector used for the random scale of numbers. A trivial solution of w = [0 0 … 0] is determine for any number X (Eq. 3). Therefore, if A is a pairwise comparison matrix of a perfectly consistent decision maker without permitting cases where X = 0, then a possible non-trivial solution can be derived from eq. (3). Thus, X = n, whilst $w = [w_1\ w_2\ \ldots.\ w_n]$. This indicates that for a consistent decision maker, the weights form $w_i$ can achieve a non-trivial solution to Eq. (3).

In cases where there is an inconsistent decision maker, where X, and then be the highest number for Eq. (3), we can label the solution as $w_{max}$. Thus, the comparisons of decision makers need to be closer to n and $w_{max}$ and w respectively. According to Saaty (2008) decision maker's consistency can be determined by how close $X_{max}$ is to n. Significantly, we can access approximate value for $w_{max}$ by following the listed steps in table 12 as suggested in Saaty's study (1990):

**Table 14: Steps in achieving the value for wmax (Adapted after Saaty, 1990)**

| Steps to Undertake | Description |
|---|---|
| 1 | Individual A's columns are estimated by dividing every entry by the in column I of matrix A by the total of column i. The leads to the production of new matrix Anorm, in which the sum of every column is equal to 1. |
| 2 | Determine the estimation for wmax, average wi of entries in row I of the new matrix (Anorm) |

## Consistency Checklist

In order to determine decision maker's consistency in relation to option comparisons, the AHP model concludes its process by employing two key steps for the final stage process.

Step 1: Calculate the Confidence Interval (CI) as in Eq. (4) and an extension to further calculate $X_{max}$ (i.e. decision maker's consistency) in Eq. (5)

**Equation 4: Confidence Interval (CI)**

$$CI = \frac{Xmax - n}{n - 1} \qquad (4)$$

**Equation 5: Decision maker's consistency Xmax**

$$Xmax = \frac{1}{n} \sum_{i=1}^{i=n} \frac{\text{ith entry in } Aw^T}{\text{ith entry in } w^T} \qquad (5)$$

Step 2: Compute the Consistency Ratio (CR), using Random Index (RI) as indicated in Table 13

Equation 6: Consistency Ratio (CR)

$$CR = \frac{CI}{RI} \tag{6}$$

RI values is computed and proposed by Saaty (1990). Thus, the Random Index is based on the size of the matrix, n x n (i.e. an indication of pairwise comparison matrix). The values generated in Table 13 are computed to provide the average CI with a condition that state that '*if the entries in A were selected at random'* subject to diagonal entries equalling 1 (equal importance) and if aij = 1/aji. With this in mind, a perfectly consistent decision maker will have consistency ratio CR = 0. However, if CR is less than 0.10 (CR<0.10), then the extent of consistency is satisfactory but if the CR is greater than zero (i.e. CR>010) then this will lead to inconsistencies in the AHP model with ambiguous results. Please find a screen shot of the AHP software template on Appendix 6.

### 4.7.3 Sensitivity Analysis

Within the AHP model (i.e. decision analysis) the sensitivity analysis was employed to determine the feasibility of key choices that impact the ranking of the policies. The study of sensitivity analysis relates to how the uncertainty in the output of a mathematical model or system can be apportioned to different sources of uncertainty in its inputs. Thus, the sensitivity analysis for the case study will be the transition in weights of the objectives of environmental and economic benefits. The weighting of the two objectives will be reformed from its current situation where each objective is given equal weights of 1, with the following outcomes:

- 50% - Environmental Impact
- 50% - Economic Impact

The transition of weights will be shown in policies, which reflect preferences for one objective. Significantly, the sensitivity analysis further shows a bias towards one objective. The weights are allocated based on Table 12. In case where the AHP model is bias towards economic impact – a weight of 3 will be observed as the environmental impact weights equal to 1.

Table 15: Sensitivity weights

| Bias | Environment | Economic |
|---|---|---|
| Environment | **85.5%** | 14.5% |
| Economic | 14.5% | **85.5%** |

### 4.7.4 Result Interpretation

Result interpretation for the entire model will be included in the case study review where the application of both LCA and AHP model will be discussed and limitations will be further discussed. The outcome of the two models will provide a complete decision support model needed to investigate the economic and environmental benefits of recycling and reuse of C&D waste.

## 4.8 Data Quality

Inputs (selected C&D wastes) and outputs ($C0_2$ emissions) vary considerably depending on recycling, reuse and landfill techniques used, processing activities, distances between transfer station, C&D waste collections etc. Thus the framework uses average figures obtain from the case studies. Although there are limitations to the applicability of using average figures, it is consistent with the purpose of incorporating LCA at a generic, policy-focused level.

The use of average data will identify the types and scales of impact categories likely to arise from C&D waste recovery/recycling target alternatives. Data in this thesis was derived from the GCC's database and analysis is carried out using the following sources discussed in the following section.

### 4.8.1 Environmental data sources

**Electricity and other energy:**

- GCC's database is sourced from a technical report provided by the company covering average UK Grid Electricity. Carbon Footprint measurement are considered for waste transfer facilities and processing.

**Waste Management (Landfill and Incineration):**

- GCC's database

- Life cycle assessment of C&D waste Management systems: A Spanish Case Study (Mercante et al., 2011)

**Materials:**

- GCC's database

**Transport:**

- GCC's database (Waste transfer vehicle emissions)
- North London, private conversation
- Sustainability in the construction industry: a review of recent developments based on LCA (Ortiz et al., 2010)

**Storage:**

- GCC's database

### 4.8.2 Economic data sources

**Net present value (NPV)**:

- GCC's database is sourced from a waste management budgetary report provided by the company covering average Life Cycle Costing (LCC).

### 4.8.3 Limitation in data

Average data are adopted for the development of the decision-support framework because of the limitation found in the methodology. As a location-specific research data collected would not be relevant to the whole of the UK construction and demolition sites. However, by using average some accuracy in the data will be lost. For the economic data sources, income for different waste activities are excluded due to data protection and confidentiality issues. Arguably, by aggregating several data sources together for the framework development, the uncertainties within the results are skyrocketed. This is as a result of unknown methodologies used by GCC's in collecting and compiling their data.

## 4.9 Summary

Chapter 4 has been able to meet its objective by examining the attributes to decision making in recycling and reuse of C&D waste an finally constructing a decision support framework needed help decision makers to understand the environment and economic benefits of recycling and reusing C&D waste. The four-stage process developed in the decision-support framework set out the following:

- The Goal and Scope
- Inventory Analysis using LCA model
- Impact Analysis through the use of LCA model
- AHP – Decision analysis

Stage 1 of the framework sought to show clarity in the overall goal, scope and limitations within the decision support model. Stage 2 continues to access waste flow inventory data using LCA model. Stage 3 explored the impact analysis, using inventory data criteria set to measure the impact of key research objectives (measurement of environmental and economic benefits). Finally, Stage 4 consults the outcome of the impact categories from Stage 3 by performing a decision analysis with the help of AHP model. At this stage the decision makers are provided a set of decision procedure that allows more consistency and organised policies alternatives to be evaluated.

# CHAPTER 5: Case Study

## Chapter Aim:

The purpose of the chapter is to put the developed decision support framework in Chapter 4 into action. Thus, the framework is to be applied to the waste management system for the two case studies.

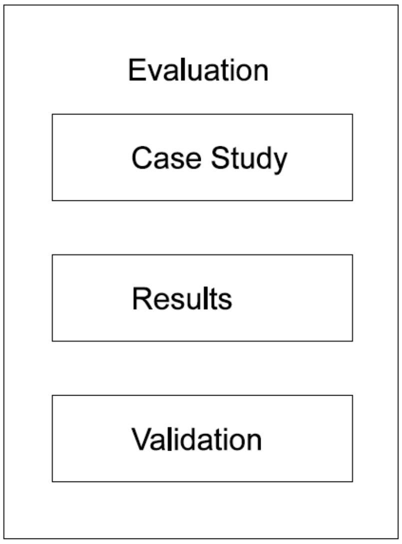


Figure 27: Evaluation

## Chapter Objectives

- **Application** of framework developed to an applicable case study
- **Assess** the framework outputs
- **Validate** outcomes

## 5.1 Orientation Guide

Chapter 2 set out the literature review with the intention to develop an academic foundation for C&D waste generation, conceptualise underlying principle of waste management and address the issue of economic and environmental impact in relation to recycling and reuse of C&D waste. The chapter further focuses on roles of waste management, overview of waste management legislation and policy and the underlying issues with legislation. Chapter 3 presents a critical review of two key management tool LCA and MCDA in order to assess the environment and economic benefits of recycling and reuse of C&D waste.

Chapter 4 has successfully established a platform to construct the decision support framework necessary to help decision makers understand goals, objectives, criterions, and available policy alternatives to be made to enable them fully appraise the economic and environment choice when considering recycling or reusing C&D waste. The development of the decision support framework in relation to assessing the environmental and economic benefits has enabled the researcher to put together possible policy alternative criteria to be considered for an effective management of C&D waste. The framework was pertained to the main case study and the four key stages were accomplished.

The decision support framework helps the decision in relation to meeting key objectives and solicits other improvement measures within the waste management system. The goal and scope of the research was outlined in stage 1 (as stated on section 4.3). Conclusively, stage 1 of the decision-support framework has already been accomplished. Thus, the results that are attained from the main case study be released in line with the three stages of the framework. However stage 2 will give results that are retrieved from waste system inventory data. Significantly, a model known as a *"flow diagram"* was developed for this information (See Figure 16).

The development of a flow diagram helps the study to complete information on the waste management system for each waste inventory data. Then, this stage further completes the process by considering all policy alternatives available to successfully assess the impact categories of LCA model. Stage 3 (i.e. impact characterisation) was completed by collecting results from Stage 2 (LCA: inventory data), which is then amalgamated such that it helps facilitate the decision support systems in terms for future recyclers, managers, academic researchers, aggregate users and other consultants.

The final stage (Stage 4: AHP: Decision Analysis) attempts to use the impact assessment obtained from stage 3 to develop a decision analysis with the support of the project managers and Construction Site Managers, who represented the Decision Makers. The help of selected Decision Makers through set criteria completes the decision procedure. At this stage the decision hierarchy framework was constructed (see Figure 24) which outlines the framework, goal and objectives, criteria, and the policy alternatives considered. The help of a "pairwise comparison" and sensitivity analysis helps to arrive at a realistic and feasible decision to effectively manage C&D waste completed stage 4.

## 5.2 Overview of the Case Study

The research considers two case studies in order to validate the final outcomes of the proposed framework. The two case studies (Medium and Small Demolition and New Build projects) are carefully selected due to the scale of project and the nature of work carried out.

### 5.2.1 Case Study 1

The first case study is a £27m Demolition and New Build project; with floor area of size 10500m$^2$ of office space spread over five floors and projected for duration of 132 weeks completion (see screen shot of project selection list on Appendix 4). The project is managed and executed by a reputable construction firm (Global Construction Company) with the main construction site located in North London, United Kingdom. Demolition works include external and internal walls, break out and excavation of the ground floor slab, removal of sections of the party walls, excavation of existing side boundary fence.

The removal of fundamental elements of the existing structure was carried out by 25 and 45 tonne excavators with specialist attachments and this was a major challenge faced by demolition contractors. Noise and vibration was considered during demolition works in residential and commercial environments nearby. Traffic management was put in place to ensure all pedestrian safety was managed. The new build project was constructed using substructure, frame, floor, roof and external walls is a block work inner skin with aluminium rain-screen cladding.

Contractors, site workers, and private waste carriers carried out the demolition activities. Two specialists (Waste Specialist A and Waste Specialist B) were involved in waste transfer directing on and off construction sites. Reclamation of building materials was carried out with greater focus on external brickwork, plain clay roofing tiles, floorboards, floor joists, window casements, doors, and furniture based on project and contractual obligations.

### 5.2.2 Case Study 2

The second case study is a £12m Demolition and New Build project; with floor area of size 2000m$^2$ of office space spread over 2 floors and projected for duration of 100 weeks completion (see screen shot of project selection list on Appendix 4). The project is managed and executed by the same firm (GCC) as case study 1. Case study 2 is located in North London. Demolition works include external and internal walls, break out and excavation of the ground floor slab, removal of sections of the party walls, excavate existing side boundary fence.

Noise and vibration was considered during demolition works in residential environments nearby. Traffic management was put in place to ensure all pedestrian safety was managed. The new build project is constructed using substructure, frame, floor, roof, and external walls. Contractors, site workers, and private waste carriers carried out the demolition activities. Two specialists (Waste Specialist C and Waste Specialist D) were involved in waste transfer directing on and off construction sites. Reclamation of building materials was carried out with greater focus on external brickwork, plain clay roofing tiles, floorboards, floor joists etc.

## 5.3 LCA: Inventory Results and Policy Development

The inventory results have been generated through Stage 2 of the framework. At this stage, inventory data on waste system was collected and analysed. Primary waste data was obtained from two main sources. First, inventory data was collected from database of the Global Construction Company (i.e. waste transfer records, recycling reports, and company’s waste management plan between periods of November 2014 to March 2015).

Second, a questionnaire was designed to capture opinions and views of key stakeholders (see screen shot of questionnaire on Appendix 7). The aim of the questionnaire is to capture views of decision makers in relation to policy alternative preferences. The data obtained from these two sources was used to develop a baseline system data, which was then stretched into different waste policy alternatives. These are considered to be beneficial for different construction groups namely, demolition contractors, recyclers, on-site waste producers’, aggregate users and other researchers.

### 5.3.1 Inventory Results

The waste system inventory result was obtained from an analysis of the five keys stages as identified in the methodology. A compilation of the inventory data was performed for the waste system, incorporating five processing (i.e. storage, transportation, disposal, recycling, and reuse) and the impact categories, which measures both economic and environmental impacts respectively. In order to compile results of the waste system a life-cycle map was developed for inventory analysis as indicated in Figure 18. The life cycle map shows the measure for both impact categories using parameters such as cost inventory (such as operations, fuel cost, and greenhouse gasses).

**Storage**

The data relating to storage obtained from the main case study provides waste quantity and location of the main demolition and construction site as well as recycling and reuses activities performed on and off site. The waste management budget of the project site in North London and waste data for the two case studies was obtained as these were projected for 1 year. This information included project value, floor area, duration of project, waste carrier consultants, waste type/group, waste code used, waste volume, tonnage, ticket number, disposal route, container type and sizes, reuse and recycling rates (i.e. in percentage and monetary terms), percentage of waste diversion from landfill etc.

Conversely, the data from the Waste Plan was obtained that shows the types of C&D reusable and recyclable wastes and their respective mass. Thus, data obtained was from November 2013 to April 2014 (Case study 1) and October 2014 to March 2015 (Case study 2), covering three key seasons (Autumn, Winter, and Spring). A continuous data sampling is therefore considered to be large enough for the requirements of the two case studies. A weighted average per month is estimated and this information was extrapolated to compute an annual total of waste processed by Waste Specialist A (Case study 1) and Waste Specialist C (Case study 2).

An assumption of standard *skip* volume of 4 cubic yards (3.06m$^3$) C&D waste density of 13.3kg/m$^3$ and skip collection rate of 90% full was made as a result of waste audits on national capped rate in the storage and collection of C&D waste. The nature of C&D waste produced is closely related to the type of work or type of building (new build and demolition project work is considered for the study). This is predominantly inert waste (i.e. waste which is neither chemically or biologically reactive and will not decompose such as sand, stone, rock and concrete which has particular relevance to landfills as inert waste typically requires lower disposal fees.

A summary of the inventory results for storage waste is listed below:

- The total amount of waste produced by the project site within six months is 409.61 tonnes for Case Study 1 and 83.45 tonnes for Case study 2.
- Waste Specialist A handles 203 tonnes of waste, 68.26 tonnes of C&D waste per month from storage, whilst Waste Specialist C handles 42 tonnes of waste, 13.9 tonnes of C&D waste per month from storage;
- 14 skips are serviced by Waste Specialist B, 12 are serviced three times per week and 2 once a week, approximately 34.54 tonnes
- 4 skips are serviced by Waste Specialist D, 3 are serviced two times per week and 1 once a week approximately, approximately 1.08 tonnes.

Table 16: Total amount of waste that is disposed for project duration (Case study 1)

| | Units | Full Mass | % full | Frequency (collection/month) | Subtotal (kg) |
|---|---|---|---|---|---|
| **C&D waste from Case study** | 12 | 41 | 90% | 76 | 33,653 |
| | 2 | 41 | 90% | 12 | 886 |
| | | | | **Total (kg)** | 34,539 |

Table 17: Total amount of waste that is disposed for project duration (Case study 2)

| | Units | Full Mass | % full | Frequency (collection/month) | Subtotal (kg) |
|---|---|---|---|---|---|
| **C&D waste from Case study** | 3 | 20 | 90% | 18 | 972 |
| | 1 | 20 | 90% | 6 | 108 |
| | | | | **Total (kg)** | 1,080 |

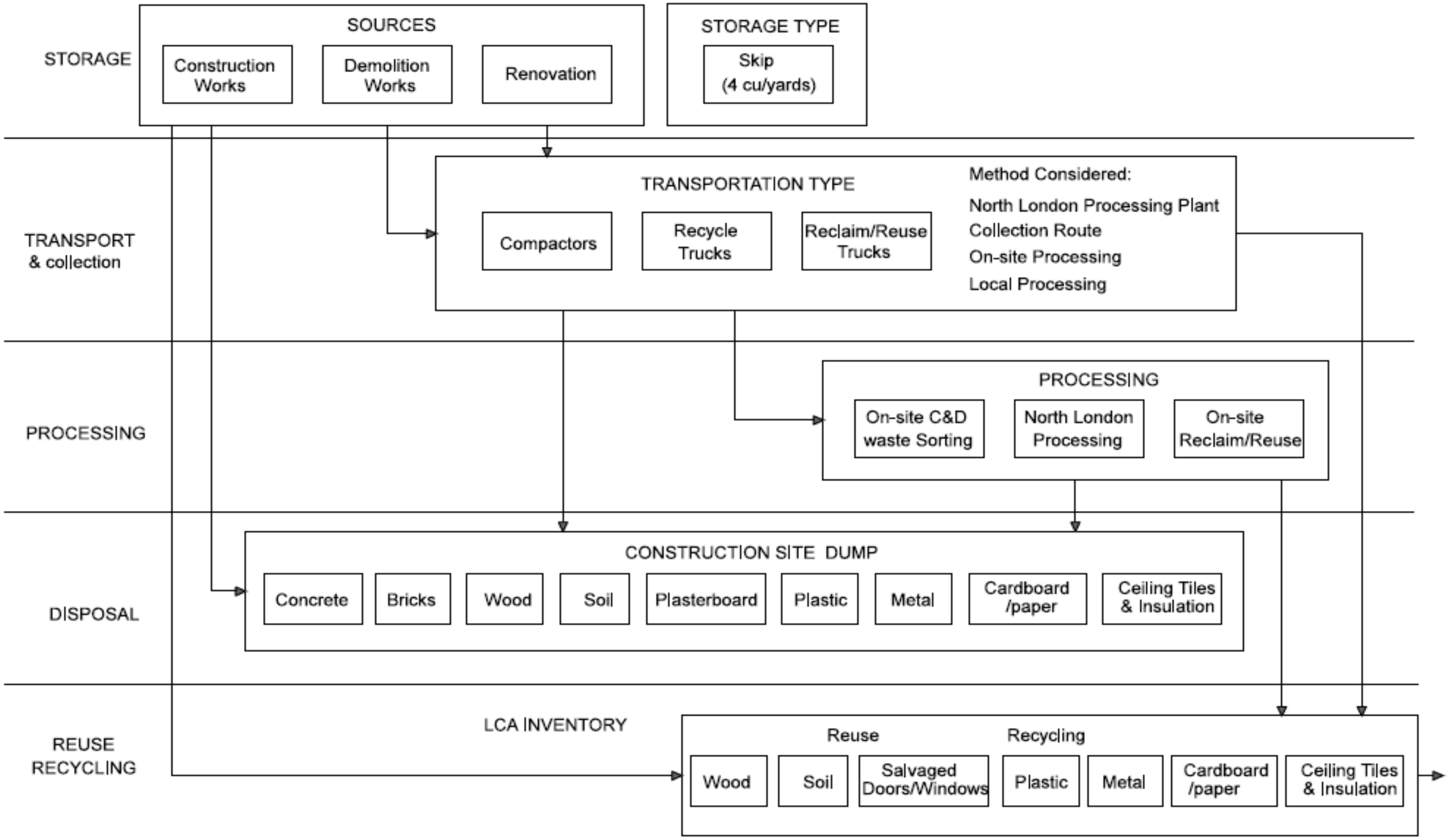


Figure 28: Waste system of present construction and demolition site (Source: LCA mapping designed by Author for Case study 1&2)

## Transportation & Collection

Inventory data for the waste system incorporates the second phase, which is the transportation and collection data. This data was deduced from the demolition site layout plan as indicated in Appendix 1. This allowed for the monthly distance travelled to be estimated. The distances and frequency of collection by construction site waste plan are shown in Tables 18 and 19 below. Thus, waste processing is carried out in two places; on-site and off-construction sites (where it is being sorted and weighed) and then transported 30 miles, to waste processing facility in North London.

Waste Specialists A and C helps the two project sites to manage waste skips and for frequent collection once or twice a week. Waste Specialist A and B are a private consultants appointed for the demolition and new build projects for Case study 1 and 2 and they carry out the collection of waste and transportation to local landfill. Other C&D wastes unprocessed are then transported to landfill which is about 10 miles for (Waste Specialist B & D). All collection of skips from the main construction site has an estimated total route of 20miles. However, all skips are processed at least twice a week due to the nature of the heavy demolition works.

Table 18: Average distances waste transported for case study 1

| Route | Responsibility | Route Distance (miles) | Frequency | Total (miles) |
|---|---|---|---|---|
| Waste Processing | Waste Specialist A | 30 | 12 | 360 |
| Landfill | Waste Specialist B | 10 | 12 | 120 |

Table 19: Average distances transported for case study 2

| Route | Responsibility | Route Distance (miles) | Frequency | Total (miles) |
|---|---|---|---|---|
| Waste Processing | Waste Specialist C | 30 | 6 | 180 |
| Landfill | Waste Specialist D | 10 | 6 | 60 |

## Processing

C&D waste has been processed both on and off-site. The processing strategy included the transfer of skips to base transfer station where full mechanical or manual sorting are performed. The North London waste sorting facility is responsible for sorting and weighing of reusable and recyclable C&D waste that has been collected from various facilities.

However, this process involved various consulting firms for transportation. This activity is run by Waste Specialists A and C. For Case study 1, 10 people were employed as on-site sorter, cleaners, and loaders with the addition of project managers to oversee the demolition works and in Case study 2 about 5 people were hired from similar process carried out in Case study 1. It is assumed that both un-reusable and un-recyclable C&D wastes are diverted to landfill for the purpose of the study.

### Disposal

The private consultancy firm known as Waste Specialists B and D are responsible for most of waste being diverted to landfill. Waste Specialist B serviced about 14 skips and 12 are serviced three times per week and 2 once a week, whilst Waste Specialist D serviced about 4 skips and 3 are serviced three times per week and 1 once a week. As estimated within the storage system data, Waste Specialist B is responsible for 34.5 tonnes of waste disposal (i.e. waste diverted to landfill) within six months project duration, and Waste Specialist D is responsible for 1.1 tonnes of waste disposal. This figure seemed similar to what Waste Specialist A and C has handled in relation to the extent of processing. However, Waste Specialist A and C do access some of the waste transfer to landfill and extracts a higher percentage for reusable and recyclable materials.

Waste Specialist A and C provided 6 months waste data including reuse and recycling report for the current project to determine the amount that goes to landfill. Thus, the estimated total of waste to landfill for Waste Specialist A is about 8 tonnes (24%) whilst the processed estimate is about 25.29 tonnes (about 76% recycling and reuse efficiency). For Waste Specialist B about 1.87 tonnes (18 %) processed estimate about 11.65 tonnes (i.e. 82% recycling and reuse efficiency). It is important to understand that waste materials from construction and demolition sources that cannot be reused or recycled on or off site are also considered for diversion to landfill.

### Reuse and Recycling

Salvage sand, soil, stones, windows, and doors lend itself to numerous reuse applications. From the construction standpoint, salvage materials have several advantages. First it recovers the highest percentages of the embodied resources in the materials or subsystems. The energy and raw materials consumed in the original manufacture of the material or systems are not lost to landfilled disposal. Second, salvaging reduces the total costs of materials since only the cost of removal, renovating, and transport are incurred by the salvage.

Waste Specialist A and C handles the largest aspect of reuse and recycling of C&D waste on and off the two project sites.  Waste Specialist A and C transfers almost all recyclable wastes to recycling facilities off site. The waste collected from construction sites are transported to North London Processing plant where it is processed, weighed, and then sent to local recyclers to further processing. Thus, the reuse and recycling activities processed by Waste Specialist A and C were considered for the research, and not C&D waste sent to landfill as facilitated by Waste Specialist B and D. Data analysis is limited to waste data on *'reuse and recycle*' handled by Waste Specialist A and C.

A total of 25.29 tonnes (Case study 1) was reused and recycled. Out of which, 6.45 tonnes (about 25% reuse efficiency) was reused and about 19.04 (recycling efficiency of 75%) was recycled.  The breakdown of C&D waste composition percentage recycled shows, 5.63% of concrete, 42.43% of soil/sand, 30.70% of plastics, 6.82% of wood, 5.41% of metal, 5.15% of cardboard/paper, 2.71% of plasterboard and 1.15% of bricks. The percentage of total waste reclaimed and/or salvaged and then reused is show below in Figure 29.

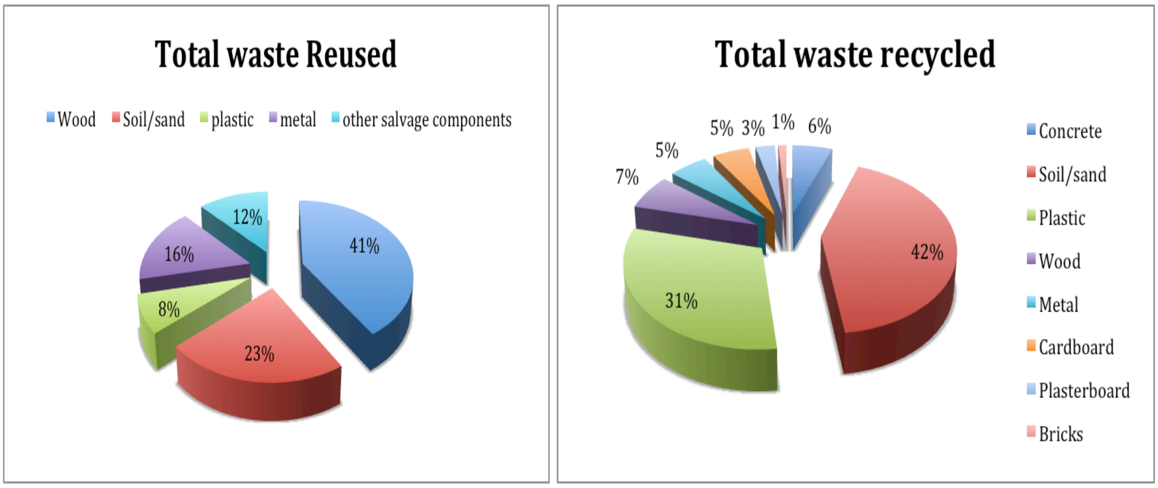


**Figure 29: Total waste reused and recycled (case study 1)**

For Case study 2, a total of 1.65 tonnes was reused and recycled. Out of which, 0.54 tonnes (about 33% reuse efficiency) was reused and about 1.11tonnes (recycling efficiency of 67%) was recycled. The breakdown of C&D waste composition percentage recycled shows, 8.40% of concrete, 23.87% of soil/sand, 50.65% of plastics, 2.65% of wood, 3.23% of metal, 7.65% of cardboard/paper, 2.74% of plasterboard and finally 0.81% of traditional bricks.

Thus, the percentage of total waste reclaimed and/or salvaged and then reused is shown below in Figure 30.

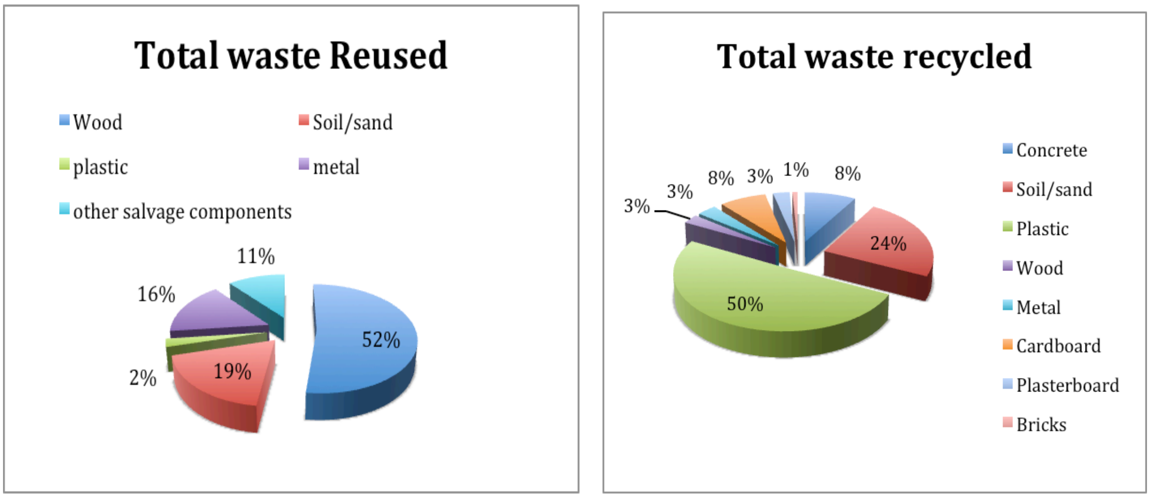


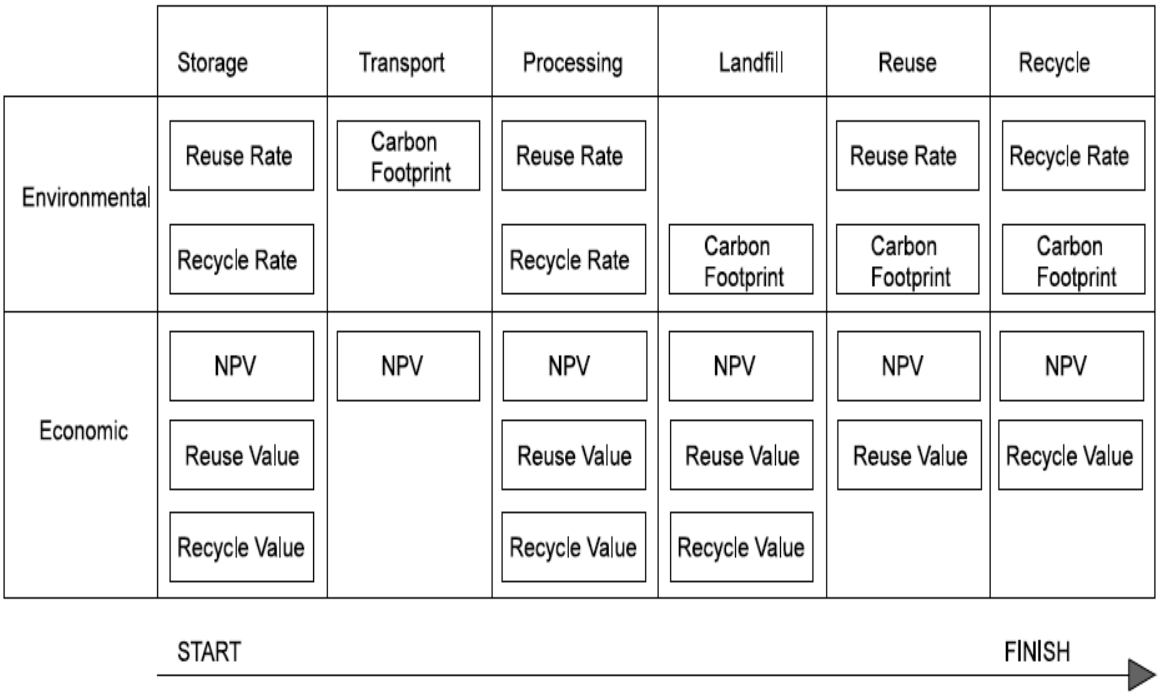
Figure 30: Total waste reused and recycled (case study 2)

### 5.3.2 Deciphering Inventory data into an Impact Analysis

Translating inventory data in impact categories will further establish the links between collected waste data and the impact analysis to be accomplished. This section explains how policy alternatives have been developed for the two case studies (i.e. Demolition and New Build project’s waste management systems). Figure 28 illustrates how the waste inventory data was assigned to the identified impact categories. Figure 31 further shows the representation of all six stages of the waste management systems for the two case studies.

#### 5.3.2.1 Results of Environmental Measure

Five waste management activities have been measured with environmental impacts. First, the reuse and recycling rate of a given waste system was investigated. This measure was observed to be influenced by individual waste type, waste quality being diverted to landfill. However, it is observed that storage and early diversion to landfill greatly influences reuse and recycling potential. Thus, strength of sorting operation as performed by Waste Specialist A and C remain the activities performed before C&D waste is diverted to recycling and reuse facilities. Second, Carbon Footprint remains a major source for transportation and then disposal, reuse, recycling activities. Other data such as distance, transportation, and vehicle capacity were recorded for the measurement of Carbon Footprint.



| | Storage | Transport | Processing | Landfill | Reuse | Recycle |
|---|---|---|---|---|---|---|
| Environmental | Reuse Rate<br>Recycle Rate | Carbon Footprint | Reuse Rate<br>Recycle Rate | Carbon Footprint | Reuse Rate<br>Carbon Footprint | Recycle Rate<br>Carbon Footprint |
| Economic | NPV<br>Reuse Value<br>Recycle Value | NPV | NPV<br>Reuse Value<br>Recycle Value | NPV<br>Reuse Value<br>Recycle Value | NPV<br>Reuse Value | NPV<br>Recycle Value |

Figure 31: The impacts categories as identified in the inventory analysis

### 5.3.2.2 Results of Economic Measure

The economic inventory was analysed by three key impact criteria measures as shown in Figure 22. The economic assessment is required of the data obtained from the two case studies in relation to NPV, recycle and reuse value. This data is made up of a private cost perspective obtained directly from GCC database. The Net present value is the operational value of a policy alternative, which represents all cash income and expenditure that are associated with C&D waste management activities. The NPV accounts for the economic performance of the waste management system through the different life cycle stages.

The economic impacts are thus observed from GCC's perspective and do not account for any cost transactions of outside parties. The economic assessment considered three key areas for NPV measure: First, the impact on different waste management strategies on the two project sites would have over 1-year period. Second, the revenue that could be generated from recycling C&D waste on and off the two project sites and third the revenue that could be generated from reusing C&D waste when salvaged from the demolition works. The recycling and reuse value of the given waste was calculated from the amount of recyclable and reusable waste, types and mass of the recyclable and reusable waste sorted was used and then multiplied by the respective prices per tonne. A screen shot of local prices of secondary materials are represented in Appendix 8. The inventory data has three main sources, namely:

- Two Demolition and New Build Projects – reuse
- Waste Specialist A and C– reuse and recycling
- Waste Specialist B and D- Landfilling

Net Present Value was adopted to measure the economic impact of the waste management system for Case study 1 and 2. NPV was influenced by each of the activities of the life cycle model as all three main sources were considered for the analysis of LCA inventory data. In order to protect privacy and adhere to confidentiality issues costs and income of the different waste activities is not included, only the total NPV is considered.

Thus, the reuse and recycling value of the waste stream was estimated from the amount of reuse and recyclable waste transferred into the waste system and which can be successful obtained for reuse and recycling purposes. Therefore, the amount of waste generated, waste types and the total mass of the reusable and recyclable processes was considered, and this was multiplied by the corresponding prices per kilogram. A sample list of secondary material prices are represented in Appendix 3.

### 5.3.3 Alternative Development

Policy alternatives are obtained from the inventory results, where 10 alternatives for waste management were developed. The alternatives adopt the waste data extrapolated from the inventory and will be used to estimate the impact measures for both environmental and economic benefits.  A detail plan was established from baseline events as represented by the inventory results. The data results are observed and documented showing about 8% of waste within the system was diverted to landfill, 70% of waste was recycled, and about 22% waste was reduced or either reused on site.

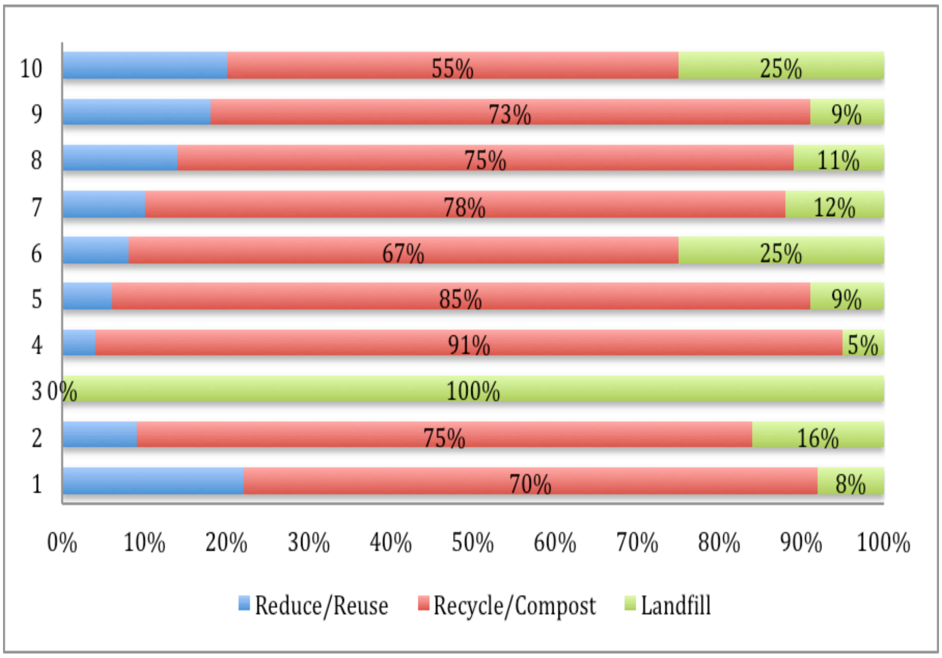


Figure 32: Established policy alternatives for Case study 1

From Figures 32 and 33, Alternatives 3 and 4 depicts the current policy on waste management. The alternatives are increasingly scaled according to the 3Rs principle of waste management hierarchy. However, Case study 2 has focused on achieving a ‘zero waste’ by drastically reducing the number of waste diverted to landfill. The policy alternatives indicated above is considered for event waste management activities and is considered as a baseline. The selection of various policy alternatives is considered with the feedback received from questionnaires obtained from professionals at the main construction site (A screen shot of the questionnaire can be found in Appendix 7). Thus, these alternatives are developed to align to the waste management hierarchy as represented in the framework. The first policy alternative for Case study 1 considers 22% waste reduced or either reused, 70% of waste recycled, and 8% of waste to be transferred to landfill.

Figure 31 also shows that 28% of waste reduced or either reused, about 67% of waste recycled and 5% of waste was diverted to landfill. Waste Specialist A and C are the main service providers who considered these alternatives. The second and fourth policy alternatives rely on Waste Specialist A and C are the main servicers of C&D waste with the 6-month period of the two projects. For Case study 1, the third policy alternative was undertaken by Waste Specialist B as there are no waste considered to be reused or recycled and all waste are diverted to landfill. In contrary, no waste was transferred to landfill for Case study 2 for third alternative, 95% of waste recycled and 5% waste reduce or either reused.

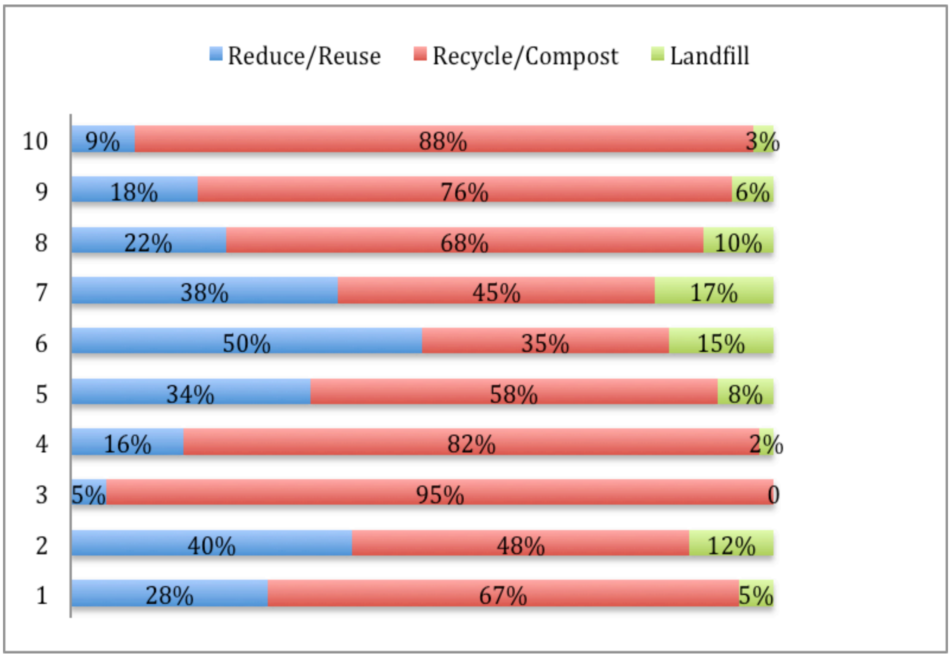


**Figure 33: Established policy alternative for case study 2**

Noticeably, for case study 1 there is an increasing waste reduction between 4 and 8 policy alternatives as recycling operations increases along the chart. The reduction of C&D waste is as result of proper management of waste on and off construction sites. However, the principle of waste minimization adopted in the case study contributes to designing-out waste philosophy. The demolition and new build projects have incorporate waste reduction principles in design and the architects have made appropriate specification to achieve this. The rate of reuse and recycling can be increased during processing and this often provides opportunities for many stakeholders at the sorting stage.

Policy alternatives 3, 6 and 10 are considered unfavourable, as there is high percentage of waste being diverted to landfill for case study 1. However, in case study 2, policy alternatives 2, 6, 7 and 8 are considered unfavourable since there is high amount of waste considered for landfill. In Case study 1, alternative 6 indicates 25% of waste has been diverted to landfill and only 8% reduction in waste was achieved. Also, policy alternative 10 have been moderately accepted having 25% of waste being sent to local landfill, however, alternative 10 has a high rate of reduction/reuse of waste. Policy alternatives to either reuse, recycle or sent waste to landfill are based on decision makers as compliance from stakeholders would be improved and promote opportunities in producing secondary materials for market value.

## 5.4 LCA: Impact Results

The application of the LCA model to the main case study is the next stage of analysis. Thus, the results obtained from the inventory study and the policy alternative there were created was considered for the analysis of case study 1 and 2 in terms of LCA impact outcomes. The LCA used the data accumulated during the inventory analysis with the intention to measure impact categories across the waste life cycle for every interphase of the waste system.

Environmental inventory was considered with special interest set of criterion 'Carbon Footprint' stated in Figures 16, 18 and 21 respectively. The key impacts were investigated during the transport, disposal, reusing and recycling activities of the waste system flow. The next criterion is the Recycling and Reuse Rate obtained from the construction site activity database. Thus, the 'rate' was only defined as the final approach of the waste management.

The economic inventory in relation to impact categories focused on the overall costs incurred for a given policy alternative. The third criterion as outlined in Figure 22 estimates the NPV of various alternatives adopted as an approach to compare the present worth of various alternatives that were presented over a 1-year period. However, Criterion 4 and 5 (see Figure 22) depicts the reuse and recycling activities. This criterion focused on the economic benefit (in terms of value) of C&D waste at the end of the reusing, recycling waste management life cycle and disposal.

### 5.4.1 Environmental Impacts

Environmental impact assessment is the formal process used to predict the environmental consequences (either positive or negative) of a plan, policy, program, or project prior to the decision to move forward with the proposed action. This reflects the environmental performance of the waste system flow. The three environmental impact measures selected are Carbon Footprint, Recycle Rate, and Reuse Rate.

#### 5.4.1.1 Carbon Footprint

The Carbon Footprint historically defines the total sets of greenhouse gas emissions caused by an organisation, event, product, or person. This is assumed to be measure for one year for the purpose of the study. The compositions of waste and travel distances are two key elements investigated for the waste life cycle. Both waste composition and travel distances greatly influence the type and output processing, disposal, reuse, and recycling activities, as this also affects $C0_2e$ of the waste life cycle of a definite alternative. Figure 32 shows the reduction in $C0_2e$ as noted from alternative 1 to 10 whilst further showing impact in three perspectives: emissions released from only waste, emissions released from transportation and emission across the waste life cycle. The alternatives shows the amount of waste diverted to landfill, amount reduced or either reused and amount of waste actually recycled.

For the analysis carried out on waste as shown in Figure 33 (red line), this leads directly to a linear decline in emissions from waste, as the increasing alternatives are investigated. In Case study 1, policy alternative 1 releases about 2.1KgC$0_2$e. per year, whilst in case study 2 alternative 1 releases about 0.8KgC$0_2$e. per year, and these two outcomes are considered a key Global Warming Impact (GWP) respectively. When comparing Alternative 1 with Alternative 10, which is considered to be a carbon sink, a high rate of reduction is achieved as more emissions are significantly prevented than are being emitted. Results of carbon reduction show negative emissions of 0.2 Kg C$0_2$e. per year.

**Table 20: Comparative view of Carbon Footprint (KgCO2e) Case study 1**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Waste life cycle | 2.7 | 2.6 | 2.3 | 2.4 | 2.3 | 2.2 | 2.1 | 1.9 | 1.7 | 1.6 |
| Waste | 2.1 | 1.5 | 1.2 | 1 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 |
| Transportation | 0.6 | 1.2 | 1.3 | 1.4 | 1.5 | 1.7 | 1.8 | 1.9 | 2.1 | 2.3 |

**Table 21: Comparative view of Carbon Footprint (KgCO2e) Case study 2**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Waste life cycle | 1.4 | 1.3 | 1.3 | 1.2 | 1 | 0.9 | 0.8 | 0.8 | 0.7 | 0.5 |
| Waste | 0.8 | 0.6 | 0.5 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |
| Transportation | 0.5 | 0.6 | 0.6 | 0.7 | 0.8 | 0.9 | 1 | 1.1 | 1.3 | 1.5 |

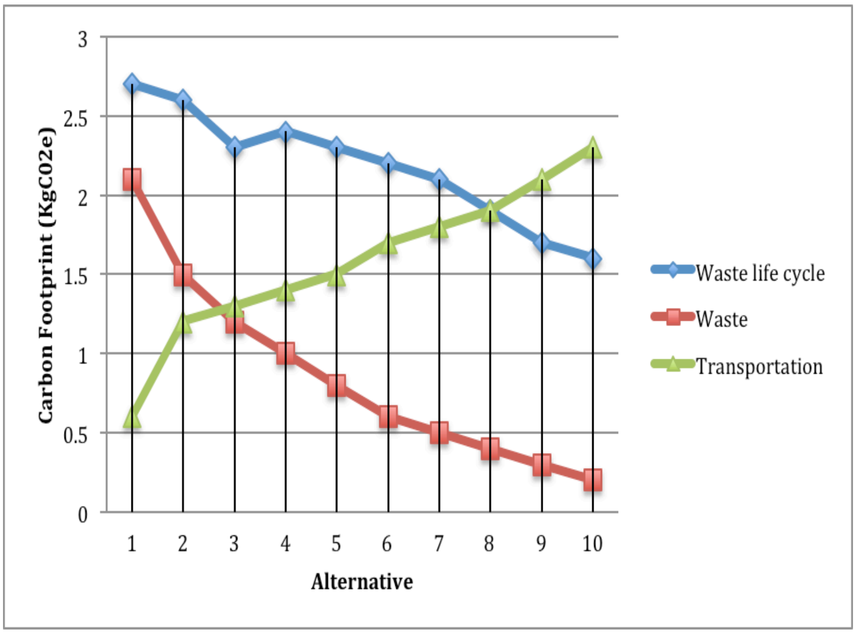


Figure 34: Carbon footprint (KgCO2e) – A comparison (Case study 1)

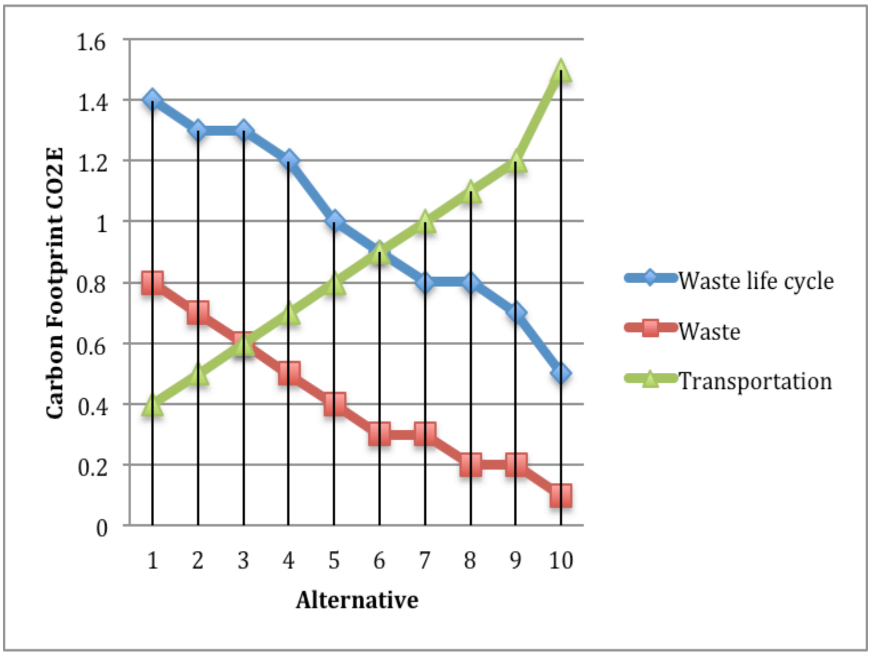


Figure 35: Carbon footprint (KgC02e) A comparison (Case study 2)

Figures 34 and 35 show estimates of emissions released from only waste with a downward trend for Case study 1 and 2. Transportation has been upset by an upward trend (green line) for the Carbon Footprint. Chase study 2 has indicated a significant improvement in the reduction of $CO_2$ as compared to Case study 1. As alternatives become moving towards reusing and recycling, the greater the distance travel covered by vehicles (trucks, loaders etc.) to get salvage materials and other waste to recycling processing facilities.

The collection process also greatly influences the decision alternatives. Alternative 2 is considered as the current baseline, which shows that transport is slightly higher source of greenhouse gases than waste, with the Carbon Footprint recorded as 1.2Kg$CO_2$e for Case study 1 and an estimate of 0.6Kg$CO_2$e for Case study 2.

**Table 22: Carbon Footprint for Reusable, Recyclable and Mixed C&D waste for Case study 1**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Recyclable waste | 0.76 | 0.85 | 0.9 | 0.93 | 0.94 | 0.97 | 1 | 1.2 | 1.5 | 1.9 |
| Reusable waste | 0.57 | 0.78 | 0.82 | 0.88 | 0.91 | 0.98 | 1.3 | 1.4 | 1.6 | 1.8 |
| Mixed C&D waste | 1.9 | 1.7 | 1.5 | 1.35 | 1.11 | 0.9 | 0.65 | 0.5 | 0.4 | 0.3 |

**Table 23: Carbon Footprint for Reusable, Recyclable and mixed C&D waste for Case study 2**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Recyclable waste | 0.45 | 0.52 | 0.63 | 0.68 | 0.74 | 0.78 | 0.84 | 0.87 | 0.96 | 1 |
| Reusable waste | 0.34 | 0.36 | 0.42 | 0.51 | 0.56 | 0.63 | 0.69 | 0.72 | 0.78 | 0.85 |
| Mixed C D waste | 1 | 0.93 | 0.89 | 0.82 | 0.76 | 0.71 | 0.68 | 0.61 | 0.53 | 0.45 |

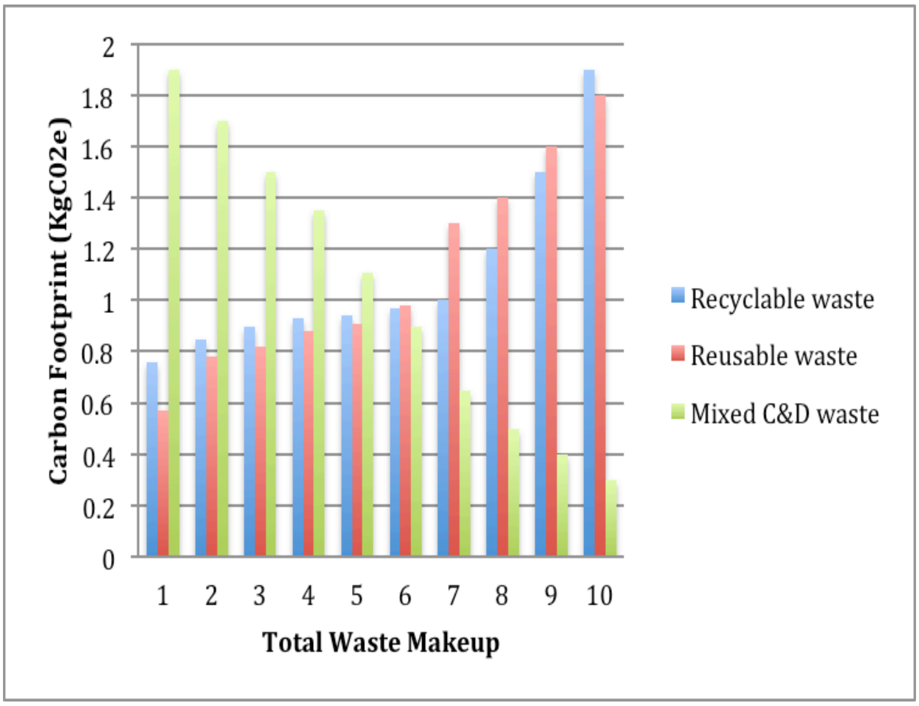


Figure 36: Carbon footprint for three types of waste for Case study 1

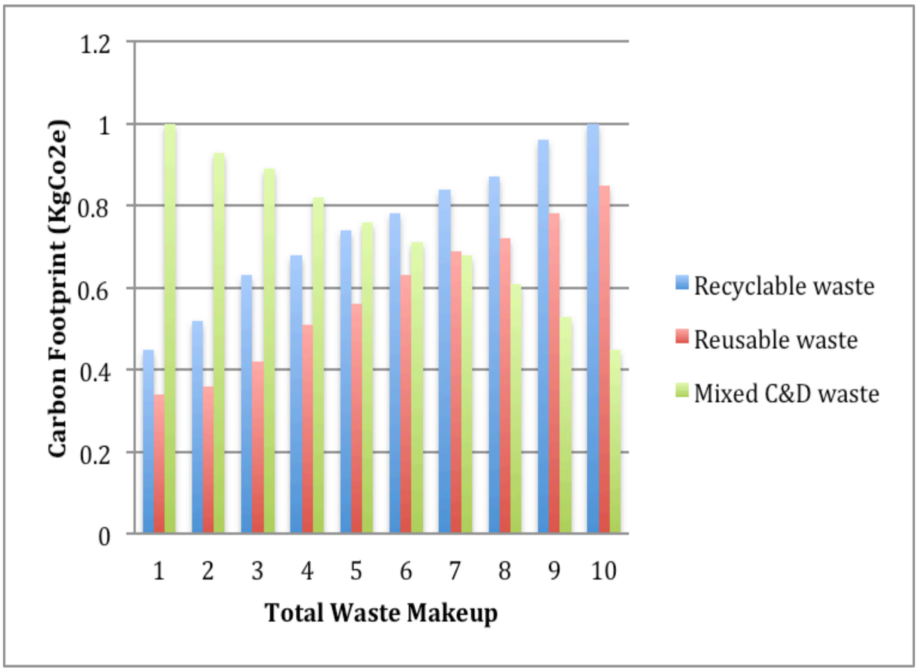


Figure 37: Carbon footprint for three types of waste for Case study 2

Further observation in Figures 36 and 37 shows that there have been a general fall in $KgCO_2e$ across all trend of difference alternative (i.e. alternative 1 to 10) for Case study 1 and 2. It indicate that by reducing waste input and fostering the amount of waste reused and recycled often result to a significant reduction in overall global warming impact of the main construction site waste system. Case study 2 has shown a significant reduction of carbon emissions due to the volume of work performed (see Figure 37 above).

Table 24: Recyclable waste carbon footprint estimate – Case study 1

**CASE STUDY 1**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Concrete | 0.76 | 0.85 | 0.9 | 0.93 | 0.94 | 0.97 | 1 | 1.2 | 1.98 | 2.76 |
| Plastics | 0.57 | 0.78 | 0.82 | 0.88 | 1.02 | 1.09 | 2.1 | 2.76 | 2.86 | 2.87 |
| Wood | 0.52 | 0.68 | 0.75 | 0.86 | 1.06 | 1.11 | 1.89 | 2.65 | 2.72 | 2.89 |
| Cardboard/Paper | 0.67 | 0.78 | 0.88 | 0.89 | 1.01 | 1.02 | 1.45 | 2.05 | 2.13 | 2.78 |
| Metal | 0.57 | 0.65 | 0.8 | 0.85 | 1.22 | 1.45 | 2.08 | 2.76 | 2.79 | 2.99 |
| Glass | 0.64 | 0.78 | 0.89 | 0.91 | 1.17 | 1.43 | 2.54 | 2.82 | 2.87 | 2.94 |
| Others Mixed waste | 1.9 | 1.7 | 1.5 | 1.35 | 1.11 | 1.54 | 2.76 | 2.83 | 2.87 | 3.25 |
| | 5.63 | 6.22 | 6.54 | 6.67 | 7.53 | 8.61 | 13.82 | 17.07 | 18.22 | 20.48 |

Table 25: Recyclable waste carbon footprint estimate – Case study 2

**CASE STUDY 2**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Concrete | 0.04 | 0.05 | 0.08 | 0.09 | 0.41 | 0.4 | 0.38 | 0.13 | 0.15 | 0.18 |
| Plastics | 0.26 | 0.16 | 0.24 | 0.18 | 0.09 | 0.19 | 0.15 | 0.35 | 0.38 | 0.39 |
| Wood | 0.03 | 0.05 | 0.19 | 0.12 | 0.08 | 0.07 | 0.04 | 0.03 | 0.04 | 0.06 |
| Cardboard/Paper | 0.02 | 0.09 | 0.07 | 0.17 | 0.1 | 0.09 | 0.08 | 0.09 | 0.08 | 0.07 |
| Metal | 0.03 | 0.13 | 0.04 | 0.11 | 0.08 | 0.06 | 0.14 | 0.16 | 0.19 | 0.15 |
| Glass | 0.01 | 0.02 | 0.03 | 0.08 | 0.06 | 0.03 | 0.05 | 0.09 | 0.08 | 0.06 |
| Others Mixed waste | 0.04 | 0.09 | 0.06 | 0.07 | 0.05 | 0.05 | 0.06 | 0.07 | 0.04 | 0.07 |
| **Total** | 0.43 | 0.59 | 0.71 | 0.82 | 0.87 | 0.89 | 0.9 | 0.92 | 0.96 | 0.98 |

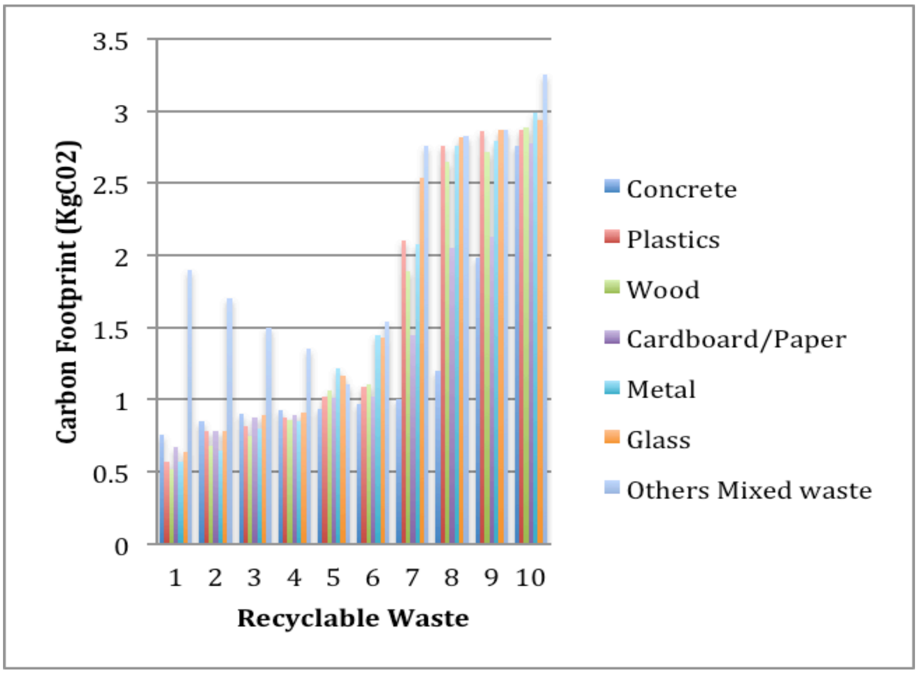


Figure 38: Specific recyclable waste KgC0$_2$e emissions for Case study 1

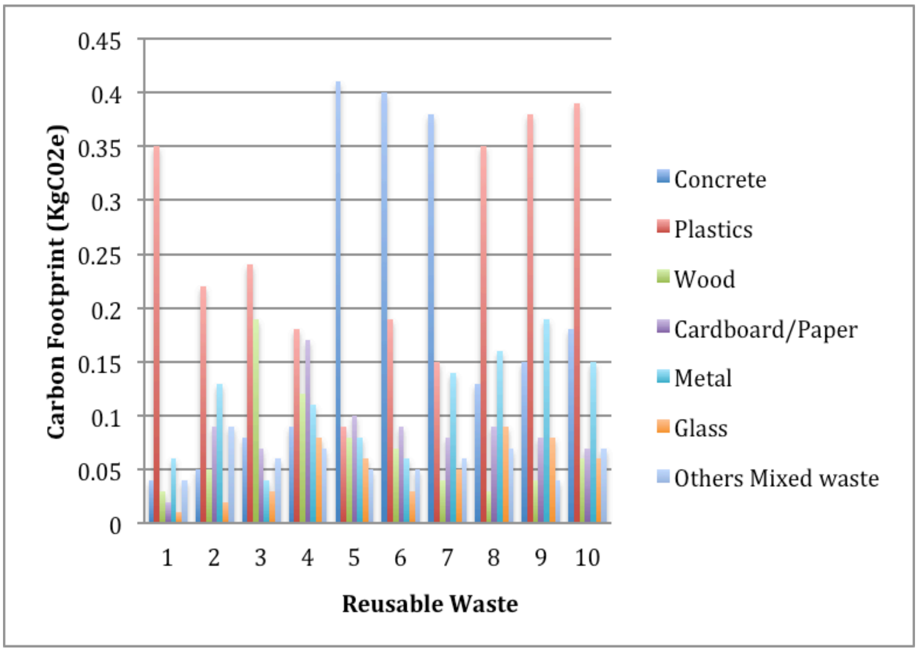


Figure 39: Specific recyclable waste KgC0$_2$e emissions for Case study 2

Figures 36, 37, 38 and 39 shows a significant fall in carbon emission in relation to waste being diverted away from landfill (i.e. for all C&D waste composition) for reuse and recycle purposes in Case study 1 and 2. A sharp downward trend is widespread in alternatives that have less waste and this consistently shows rise in $KgCO_2e$. emissions at a much denser rate as compared to reusing or recycling. The standard carbon emissions for an ideal scenerio is to be seen at it lowest value which can be demonstrated in alternative 10 (0.3$KgCO_2e$.) in Case study 1 and 0.23$KgCO_2e$.

In Case study 1, Figure 36 shows the result for mixed C&D waste. Result of this estimate shows a decrease of 41% in Case study 1, from 2.7$KgCO_2e$. to 1.6 $KgCO_2e$. per year '*waste life cycle'* and as in '*waste only'* observed to be within the range of 2.1$KgCO_2e$. to 0.2$KgCO_2e$. per year respectively. In Case study 2, Figure 37 shows an estimate of about 62% reduction of Carbon footprint from 1.4 $KgCO_2e$. to about 0.5$KgCO_2e$ '*waste life cycle'* and as in '*waste only'* observed to be within the range of 0.8$KgCO_2e$. to 0.1$KgCO_2e$. per year respectively.

Looking closely at the emissions increase for reuse and recycling in Figure 34 and 35 the significant reduction in greenhouse gas emission is directly from landfill and necessarily reuse or recycling activities and this was assumed in the study. Results shows that the Carbon Footprint levels decline from 1.9 $KgCO_2e$. per year to about 0.3 $KgCO_2e$. per year.

For Case study 1 and 2 further reduction was seen at about 1.5$KgCO_2e$. per year to about 0.23$KgCO_2e$. This observation from field study shows a significant reduction of greenhouse gases for waste. For Figures 38 and 39 the major contributor to greenhouse gases are wood, concrete, plastics, glass, metal and paper. Major attributes to this fact is the idea of travel distances covered to transport reusable and recyclable waste materials.

#### 5.4.1.2 Recycle Rate

Recycle rates of C&D waste generated in the two project sites (Case study 1 and 2). These are measured by the C&D waste operations. This accounts for the amount of waste that is recycled for each alternative in respective cases. The significant impact is influenced by the efficiency of waste recycling processes as performed by Waste Specialist A and C. Key findings on impact of rate of recycling operations are shown in Tables 24, 25, 26 and 27 respectively.

Table 26: Rate of recycling C&D waste – Case study 1

| | Total Waste (Tonnes) | Total Waste Recycled (Tonnes) | Rate of Recycling (%) |
|---|---|---|---|
| Concrete | 8.61 | 0.56 | 7% |
| Plastics | 0.96 | 0.96 | 100% |
| Wood | 2.87 | 2.05 | 71% |
| Cardboard/Paper | 0.88 | 0.85 | 97% |
| Metal | 4.62 | 0.54 | 12% |
| Glass | 1.67 | 0.56 | 34% |
| Plasterboard | 1.96 | 1.06 | 54% |
| Soil/Sand | 12.97 | 4.24 | 33% |
| **Total Waste Processed** | **34.54** | | |

Table 27: Rate of recycling C&D waste – Case study 2

| | Total Waste (Tonnes) | Total Waste Recycled (Tonnes) | Rate of Recycling (%) |
|---|---|---|---|
| Concrete | 0.03 | 0.02 | 67% |
| Plastics | 0.92 | 0.92 | 100% |
| Wood | 0.02 | 0.02 | 100% |
| Cardboard/Paper | 0.01 | 0.01 | 100% |
| Metal | 0.02 | 0.01 | 50% |
| Glass | 0.01 | 0.01 | 100% |
| Plasterboard | 0.03 | 0.02 | 67% |
| Soil/Sand | 0.04 | 0.02 | 50% |
| **Total Waste Processed** | **1.08** | | |

Table 28: The recycling rate and relative efficiency – Case study 1

| Alternative | Total Waste | Total Waste Recycled | Recycle Rate (%) | Efficiency |
|---|---|---|---|---|
| 1 | 34.5 | 5.63 | 16% | **LOW** |
| 2 | 34.5 | 6.22 | 18% | |
| 3 | 34.5 | 6.54 | 19% | |
| 4 | 34.5 | 6.67 | 19% | |
| 5 | 34.5 | 7.53 | 22% | |
| 6 | 34.5 | 8.61 | 25% | |
| 7 | 34.5 | 13.82 | 40% | **MEDIUM** |
| 8 | 34.5 | 17.07 | 49% | |
| 9 | 34.5 | 18.22 | 53% | **HIGH** |
| 10 | 34.5 | 20.48 | 59% | |

Table 29: The recycling rate and relative efficiency – Case study 2

| Alternative | Total Waste | Total Waste Recycled | Recycle Rate (%) | Efficiency |
|---|---|---|---|---|
| 1 | 1.1 | 0.43 | 39% | LOW |
| 2 | 1.1 | 0.59 | 54% | MEDIUM |
| 3 | 1.1 | 0.71 | 65% | |
| 4 | 1.1 | 0.82 | 75% | HIGH |
| 5 | 1.1 | 0.87 | 79% | |
| 6 | 1.1 | 0.89 | 81% | |
| 7 | 1.1 | 0.9 | 82% | |
| 8 | 1.1 | 0.92 | 84% | |
| 9 | 1.1 | 0.96 | 87% | |
| 10 | 1.1 | 0.96 | 89% | |

The results obtained for recycling activities for the two case studies need an input of its relative efficiency within the waste system with an exception of the efficiency relating to waste only. For Case study 1 and 2, alternative 2 and alternative 9 fully depicts the current waste system as a *baseline*; however, it shows a limited fraction of about 18% and 53% (Case study 1) and 54% and 87% of C&D waste considered to be recycled for Case study 2 as indicated in Tables 28 and 29. Values were generated from recycling rates from the overall waste management system (WMS) observed as part of the activities of the life-cycle mapping. This simply indicates that the two alternatives therefore represents low to medium efficiency rate in Case study 1 and medium to high efficiency rate in Case study 2. It is noted that the increase in recycling results brings about the alternative increase as it positively correlates with a strong relationship.

Table 30: Recycle/reuse efficiency from established policy alternative - Case study 1

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Recycle/reuse** | 92% | 84% | 0% | 95% | 91% | 75% | 88% | 89% | 91% | 75% |
| **Landfill** | 8% | 16% | 100% | 5% | 9% | 25% | 12% | 11% | 9% | 25% |
| **%Total** | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

Table 31: Recycle/reuse efficiency from established policy alternative - Case study 2

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Landfill** | 5% | 12% | 0% | 2% | 8% | 15% | 17% | 10% | 6% | 3% |
| **Recycle** | 95% | 88% | 100% | 98% | 92% | 85% | 83% | 90% | 94% | 97% |
| **%Total** | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

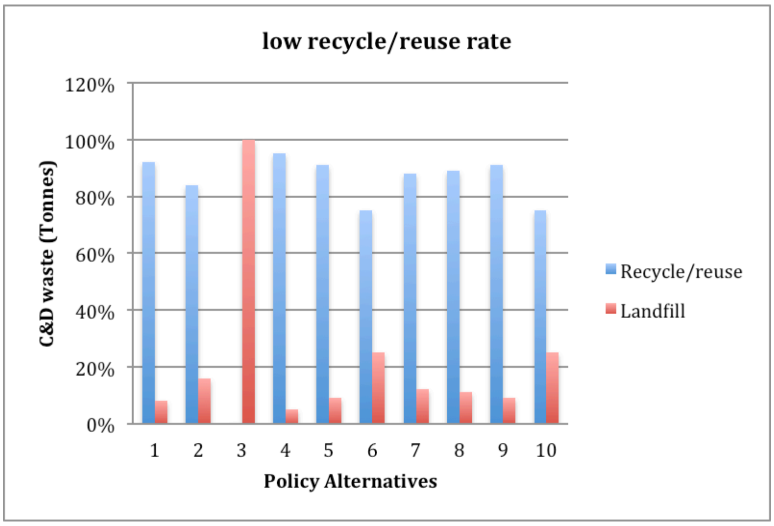


Figure 40: Recycle/reuse rate show low efficiency - Case study 1

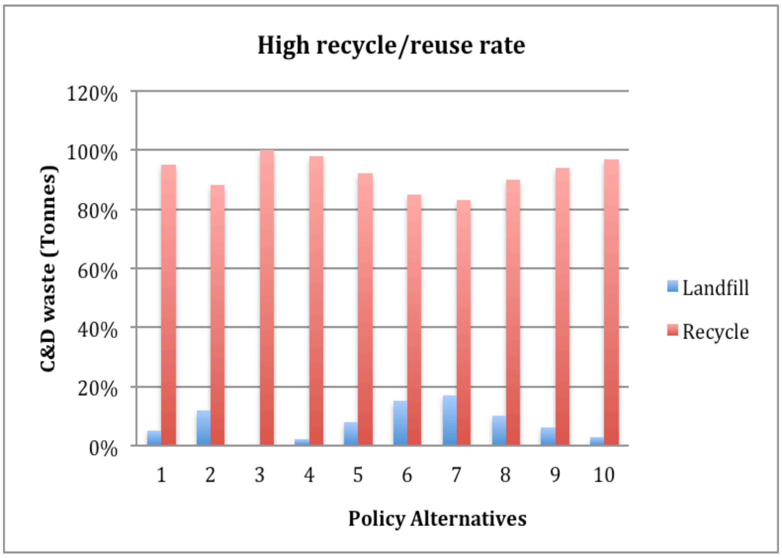


Figure 41: Recycle/reuse rate shows high efficiency - Case study 2

Figures 40 and 41 shows the amount of C&D waste that requires to be recovered from the waste system. However, this seemed possible as the transition between C&D waste reused and recycled and that sent to landfill shows an upward and downward fluctuating trend between 8% and 100 % and 5% and 25% for alternative 1 to 10 in Case study 1. This simply implies that there are low recycle/reuse rates in Case study 1 (C&D waste processing). From close observation, it is clear that in Case study 1, Alternatives 1, 4 and 9 indicates high rate of reuse and recycling within C&D waste system. However, in Case study 2 a higher rate of reuse and recycling was noted as the Demolition sand New build project have successfully reduced the number of C&D waste going to landfill (Figure 39). As individual alternatives being developed for the two case studies, greater focus and opportunities move towards the creation of jobs, training facilities, education, and enhancement of the internal efficiency of both reusing and recycling C&D waste for the two case studies. Potential C&D waste generators such as labourers, roofers, bricklayers, electrical and plumbing technicians, contractors, would have to be the main drivers of C&D waste.

#### 5.4.1.3 Reuse Rate

Reuse rate is determined by Equation (1) formulated in the methodology chapter and this has been applied to the two case studies. The reuse rate estimated accounts for the amount of waste that is reclaimed/salvaged and then reused for individual policy alternatives. The significant impacts from both case studies are influenced by the efficiency of waste reuse processes, which are decided directly on the project sites by Waste Specialist A and C. Tables 32 and 33 below show the impact of rate of reuse operations for specific waste types in the entire system.

**Table 32: Reusable C&D waste - Case study 1**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Plastics | 0.04 | 0.03 | 0.08 | 0.87 | 0.94 | 1.23 | 1 | 0.98 | 1.23 | 1.5 |
| Wood | 0.35 | 1.23 | 1.32 | 1.45 | 1.23 | 1.53 | 1.66 | 2.76 | 3.09 | 2.89 |
| Metal | 0.09 | 0.11 | 0.34 | 0.36 | 0.12 | 0.27 | 0.54 | 0.65 | 2.34 | 1.43 |
| Soil/Sand | 0.88 | 1.43 | 1.46 | 1.52 | 2.76 | 1.89 | 3.98 | 3.34 | 2.78 | 3.09 |
| Other Salvage components (window casement, door units, furniture etc.) | 0.09 | 0.32 | 1.06 | 1.23 | 1.46 | 2.06 | 2.08 | 1.98 | 1.53 | 2.89 |
| **Total** | 1.45 | 3.12 | 4.26 | 5.43 | 6.51 | 6.98 | 9.26 | 9.71 | 10.97 | 11.8 |

**Table 33: Reusable C&D waste - Case study 2**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Plastics | 0.01 | 0.03 | 0.01 | 0.04 | 0.06 | 0.05 | 0.03 | 0.04 | 0.03 | 0.06 |
| Wood | 0.06 | 0.08 | 0.04 | 0.08 | 0.06 | 0.08 | 0.06 | 0.05 | 0.06 | 0.08 |
| Metal | 0.01 | 0.03 | 0.01 | 0.02 | 0.08 | 0.09 | 0.04 | 0.02 | 0.05 | 0.07 |
| Soil/Sand | 0.51 | 0.32 | 0.31 | 0.34 | 0.23 | 0.18 | 0.13 | 0.25 | 0.17 | 0.19 |
| Other Salvage components (window casement, door units, furnitures etc.) | 0.08 | 0.33 | 0.06 | 0.11 | 0.21 | 0.35 | 0.51 | 0.45 | 0.53 | 0.55 |
| **Total** | 0.67 | 0.79 | 0.43 | 0.59 | 0.64 | 0.75 | 0.77 | 0.81 | 0.84 | 0.95 |

Table 34: The reuse rate and relative efficiency – Case study 1

| Alternative | Total Waste | Total Waste Reused | Reuse Rate (%) | Efficiency |
|---|---|---|---|---|
| 1 | 34.5 | 1.45 | 4% | LOW |
| 2 | 34.5 | 3.15 | 9% | |
| 3 | 34.5 | 4.26 | 12% | |
| 4 | 34.5 | 5.43 | 16% | |
| 5 | 34.5 | 6.51 | 19% | |
| 6 | 34.5 | 6.98 | 20% | |
| 7 | 34.5 | 9.26 | 27% | |
| 8 | 34.5 | 9.71 | 28% | MEDIUM |
| 9 | 34.5 | 10.97 | 32% | |
| 10 | 34.5 | 11.8 | 34% | |

Table 35: The reuse rate and relative efficiency – Case study 2

| Alternative | Total Waste | Total Waste Reused | Reuse Rate (%) | Efficiency |
|---|---|---|---|---|
| 3 | 1.1 | 0.43 | 39% | LOW |
| 4 | 1.1 | 0.59 | 54% | MEDIUM |
| 5 | 1.1 | 0.64 | 58% | |
| 1 | 1.1 | 0.67 | 61% | |
| 6 | 1.1 | 0.75 | 68% | HIGH |
| 7 | 1.1 | 0.77 | 70% | |
| 2 | 1.1 | 0.79 | 72% | |
| 8 | 1.1 | 0.81 | 74% | |
| 9 | 1.1 | 0.84 | 76% | |
| 10 | 1.1 | 0.95 | 86% | |

Tables 34 and 35 show the efficiency level of various policy alternatives. In Table 34, alternatives 8 to 10 show a medium efficient rate at reusing C&D waste material whilst alternatives 1 through to 7 show a low efficiency rate for Case Study 1. This simply shows that that there are opportunities in selecting options from 8 up to 10 as compared to alternatives 1 to 7, enabling key impact measures. In Table 35, result of Case study 2 gave a different and impressive outcome in terms of efficiency rates where policy alternatives 2, 6, 7, 8, 9 and 10 clearly show a high efficiency rate, whereas alternatives 1, 4 and 5 show medium efficiency reuse rates.

### 5.4.2 Economic Impacts

The economic impacts that were derived from the waste inventory data concentrate on three key perspectives as indicated in Figure 22. These key perspectives are identified and expanded as follows:

- The impact on different waste management strategies on the two project sites would have over 1-year period.
- The revenue that could be generated from recycling C&D waste on and off the two project sites.
- The revenue that could be generated from reusing C&D waste when salvaged from the local demolition works.

#### 5.4.2.1 Net Present Value (NPV)

The NPV was used for the study to measure the economic contribution of the identified waste system, which is studied for 1-year period. Table 36 and Figure 42 illustrate the comparative value of NPV for different alternatives for Case study 1 and 2.

Table 36: Tabulation for a comparative view of NPV for different Alternatives – Case study 1 and 2

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Waste Specialist A (£)** | 18.08 | 17.06 | 16.87 | 16.07 | 15.34 | 15.09 | 14.87 | 13.76 | 12.65 | 12.01 |
| **Waste Specialist B (£)** | 12.79 | 12.87 | 12.67 | 13.75 | 14.08 | 13.09 | 12.98 | 13.96 | 14.67 | 16.54 |
| **Waste Specialist C (£)** | 10.65 | 11.94 | 12.05 | 16.09 | 15.78 | 17.86 | 20.67 | 22.46 | 23.76 | 26.86 |
| **Waste Specialist D (£)** | 19.08 | 18.09 | 16.87 | 16.87 | 16.06 | 15.76 | 14.43 | 13.65 | 12.65 | 13.54 |
| **North London Processing (£)** | 9.79 | 10.98 | 11.45 | 12.09 | 12.78 | 12.98 | 12.87 | 14.56 | 14.09 | 16.43 |
| **Case study 1: Medium scale Demolition & New Build (£)** | 2.7 | 3.1 | 3.8 | 4.2 | 5.2 | 4.8 | 5.4 | 6.9 | 7.2 | 8.8 |
| **Case study 2: Small-scale Demolition & New Build (£)** | 0.6 | 0.7 | 0.9 | 1.1 | 1.3 | 1.4 | 1.8 | 2.1 | 2.5 | 3.2 |
| **Total NPV** | **73.69** | **74.74** | **74.61** | **80.17** | **80.54** | **80.98** | **83.02** | **87.39** | **87.52** | **97.38** |

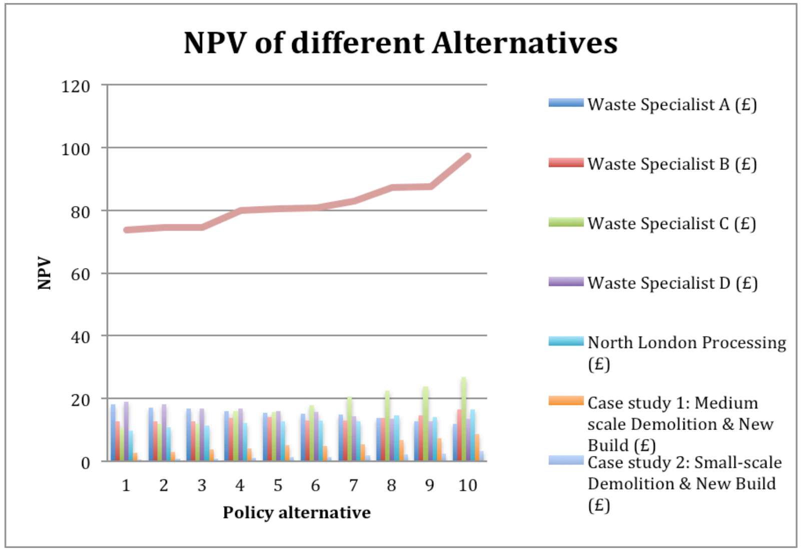


Figure 42: A comparative analysis of NPV for different policy alternatives

The main cost centres were identified as Demolition and New Build Projects (Case Studies 1 and 2), Waste Specialist A, Waste Specialist B and North London Waste Processing (landfilling dump site). These cost variations are computed and represented in impacts categories in the inventory analysis as shown in Figure 31. The NPV has been scaled and considered for various policy alternatives due to data confidentiality using GCC data. Table 36 and Figure 41 shows the increase in cost in terms of NPV as alternatives begin to progress towards a reduction in costs and reuse and recycling opportunities.

From Figure 42, alternatives 3 and 4 show different values, since there is a sharp reduction in the estimated NPV along the red line. This is due to the decrease of about 5% in NPV along the curve. The implication this has is that the financial implication for managing C&D waste for Case study 1 and 2 is considerably moderate. Figure 42 shows increase in costs as alternatives begin to progress towards reduction and recycling intensive waste management systems. An exception can be noted in policy alternative 3 and 4. The two alternatives were the first to include source reduction. This cost reduction is compared with alternatives selected by Waste Specialists A, B, C and D as well as North London Processing as part of the GCC database. Data collected from the identified source was compiled and later analysed as aggregate values used for the Net Present Value.

Waste Specialist B and D are responsible of transporting waste to local landfill accounts for the highest costs for alternative 1. Since almost all waste has been diverted to landfills there is an indication of a zero approach to waste management alternative. Also, the higher the reuse and recycling rates lined with alternatives 3 to 10, the lower the associated costs towards the value for Waste Specialist B and D. Figure 42 shows the value of NPV for the current waste management performance at both project sites. Waste Specialists A and C therefore become the dominant cost centre from policy alternative 6, taking over from Waste Specialists B and D.

Alternative 3 indicates a 5% decrease in the NPV from the established baseline as a result of special focus on waste minimisation goals. However, the number of C&D waste skips further shows the reduction in waste in the waste system. There has been an increase in NPV from alternatives 6 to 10. The waste contractors (Waste Specialists A and C) and the Demolition and New Build projects (Case Studies 1 and 2) have focused on waste reduction and considered more reusing and recycling of C&D waste.

### 5.4.2.2 Recycling and Reuse Value

The second aspect of measuring the economic impact of reuse and recycling of C&D waste is the ‘Recycling and Reuse Value’, which is a key part of the waste management system (MWS). The case studies analysed in this chapter have spent time considering reusing and recycling C&D waste generated through constant daily work on site. The revenue generated through recycling operations is estimated for over a year. This value simply clarifies a distinction between the wanted waste and the unwanted waste composition. However, this gives awareness in training, recovery rate and the opportunities in terms of value for money and job creation.

Figure 41 show the value of waste in terms of value gained and lost through reusing and recycling operations within a given waste system. The increase in value of recycling can be measured by the quality of waste sent to landfill, the level of education, training, and awareness on waste minimisation can determine the quality and extent of recycling and reuse of waste. Thus, the total value gained through recycling and reuse of C&D waste in Case Study 1 sharply increases in a linear form (i.e. £23 in alternative 1 to under £30 in alternative 10). In Case Study 2, total value gained through recycling and reuse of C&D waste increased from £13 in alternative 1 to £20 and significantly decline to £8 in alternative 10.

Table 37: Tabulation for recycle value for a given year – Case study 1

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Value Lost (£) | 22.6 | 20.07 | 19.07 | 17.89 | 16.08 | 15.04 | 11.06 | 9.87 | 6.23 | 5.03 |
| Value Gained (£) | 22.6 | 24.67 | 25.09 | 26.89 | 27.07 | 26.67 | 27.84 | 27.92 | 28.56 | 29.07 |
| **Total Value (£)** | 45.2 | 44.74 | 44.16 | 44.78 | 43.15 | 41.71 | 38.9 | 37.79 | 34.79 | 34.1 |

Table 38: Tabulation for recycle value for a given year – Case study 2

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Value Lost (£) | 12.8 | 13.45 | 5.78 | 13.78 | 12.56 | 16.45 | 5.67 | 3.54 | 3.24 | 0.45 |
| Value Gained (£) | 12.8 | 14.67 | 5.67 | 9.88 | 16.89 | 19.54 | 13.23 | 11.76 | 9.67 | 7.86 |
| **Total Value (£)** | 25.6 | 28.12 | 11.45 | 23.66 | 29.45 | 35.99 | 18.9 | 15.3 | 12.91 | 8.31 |

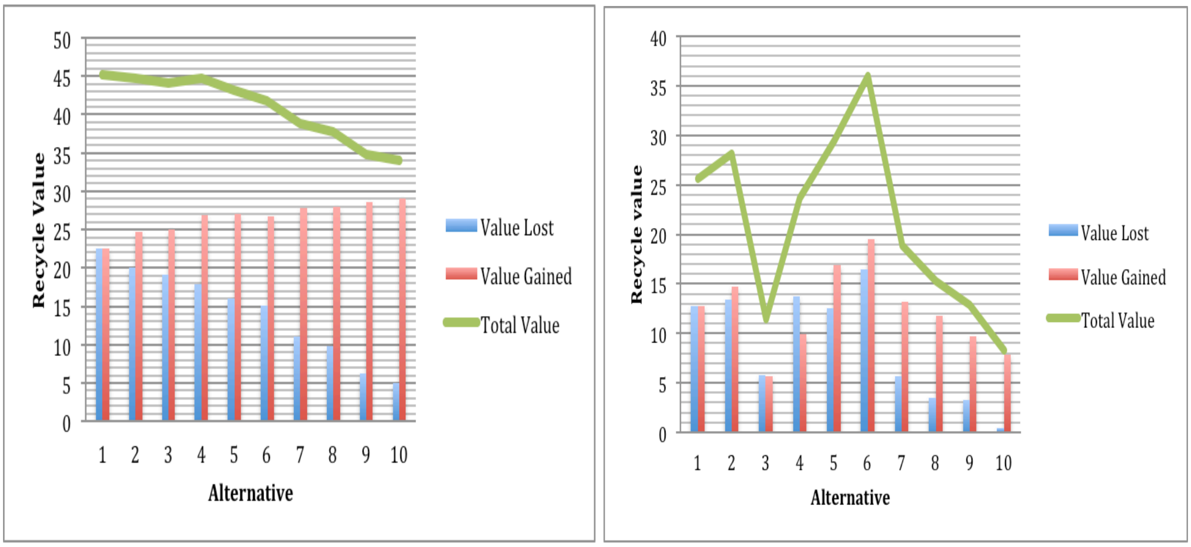


Figure 43: Value of recycling for a given year for case study 1 and 2

Figure 43 compares the total value gained and lost for the two case studies. It is clear that there is a sharp decline in value gained in alternative 3 for Case Study 2. However, the recycling operation gained momentum, as indicated in alternatives 6 to 9, yet declined in value at alternative 10. Reuse values for the two case studies are illustrated in Figure 44, which shows the value gained from reusing salvage and reclaiming C&D waste.

Table 39: Tabulation for reuse value for a given year – Case study 1

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Value Lost (£) | 18.67 | 16.45 | 15.34 | 14.64 | 13.23 | 12.08 | 11.06 | 8.45 | 6.78 | 4.87 |
| Value Gained (£) | 20.65 | 21.43 | 26.78 | 27.04 | 27.89 | 26.67 | 28.07 | 28.54 | 28.98 | 29.76 |
| **Total Value (£)** | 39.32 | 37.88 | 42.12 | 41.68 | 41.12 | 38.75 | 39.13 | 36.99 | 35.76 | 34.63 |

Table 40: Tabulation for reuse for a given year Case study 2

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Value Lost (£) | 9.76 | 11.09 | 15.34 | 14.64 | 13.23 | 12.08 | 11.06 | 8.45 | 6.78 | 4.87 |
| Value Gained (£) | 11.65 | 12.98 | 5.54 | 6.75 | 10.98 | 19.76 | 11.76 | 10.09 | 9.87 | 5.87 |
| **Total Value (£)** | 21.41 | 24.07 | 20.88 | 21.39 | 24.21 | 31.84 | 22.82 | 18.54 | 16.65 | 10.74 |

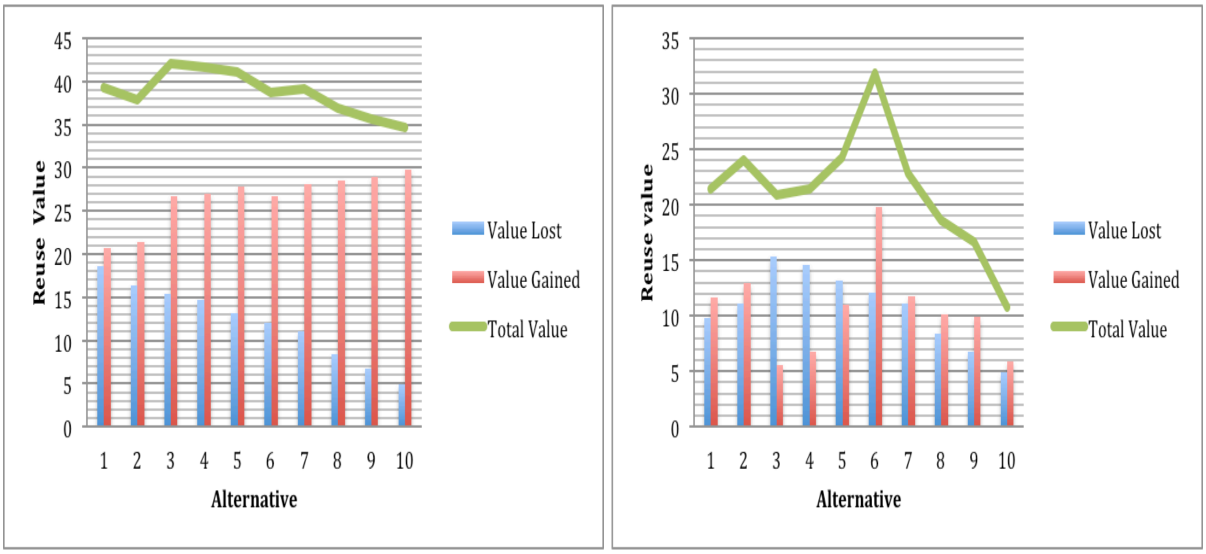


Figure 44: Value of waste material reuse for a given year

Table 37 and 38 shows the value of waste for selected policy alternatives involving reuse values are drawn from national cost value aggregate (See appendix 3). From Figure 43, it is observed that alternatives 10 and 6 have the highest value gained from Case Studies 1 and 2, which can be directly obtained from the waste system for the two case studies at an estimate of (Case study 1) £30,000 per year and (Case study 2) £20,000 per year. For case study 1 approximately £5,000 worth of C&D waste is being diverted to landfills whilst in Case study 2 about £1500 worth of C&D waste disposed in landfill, which results in a significant amount seen at baseline alternatives for the two case studies. However, the baseline shows that the amount of waste being diverted to landfills is moderately lower on a yearly basis.

Arguably, the rate of reuse and recycling operations have greatly contributed to job creation, as indicated in Figures 40 and 41, in terms of looking deeply at other related impacts. This shows that the higher the rate of reuse and recycling of C&D waste within a waste system, the higher the job creation potential as a large number of people are employed during this process. Tables 41 and 42 shows the breakdown of different types of recyclable waste and the opportunities within this process.

The correlation between the different policy alternatives in relation to the value of waste produced during the Demolition and New Build projects (Case Studies 1 and 2) has encouraged the idea of recycling on and/or off the project sites. In Case Study 1, alternative 10 shows a value of £29,567 as part of the revenue that can be generated from recycling plastics, as shown in Table 41. In Case Study 2, alternative 10 shows a value of £19,856 revenue generated from recycling plastics (see Table 42). This indicates that there are potential values in recycling and reusing waste in a given waste system.

However, value gained from producing a secondary material (i.e. recyclable waste), in monetary terms, can be a valuable resource to finance the high price of carrying out a more preventive action that will adopt a policy alternative to support reuse and recycling of C&D waste. Tables 41 & 42 show the value of waste for selected policy alternatives; these values are drawn from national cost value aggregate (screen shot can be found in Appendix 3).

**Table 41: Value of waste for alternative 2, 5, 6, 7, 8 and 10 – Case study 1**

| | 2 | 5 | 6 | 8 | 10 |
|---|---|---|---|---|---|
| **Paper** | £20,000 | £22,500 | £24,367 | £25,578 | 28,453 |
| **Metal** | £24,000 | £25,976 | £26,453 | £27,765 | 27,990 |
| **Mixed-energy recovery** | £18,564 | £20,570 | £22,542 | £24,567 | £25,003 |
| **Aluminium** | £28,456 | £28,658 | £28,786 | £28,896 | £29,087 |
| **Plastics** | £25,098 | £26,456 | £27,564 | £28,456 | **29,567** |
| **Wood** | £8,000 | £8,674 | £9,054 | £9,657 | £10,007 |

**Table 42: Value of C&D waste for alternative 1,4, 8, 9 and 10 – Case study 2**

| | 1 | 4 | 8 | 9 | 10 |
|---|---|---|---|---|---|
| **Paper** | £10,000 | £10,580 | £11,398 | £14,508 | £15,003 |
| **Metal** | £11,000 | £11,872 | £11,992 | £13,876 | £14,345 |
| **Mixed-energy recovery** | £12,005 | £13,173 | £13,246 | £14,087 | £14,006 |
| **Aluminium** | £4,409 | £6,656 | £8,774 | £10,225 | £10,299 |
| **Plastics** | £11,114 | £12,136 | £14,204 | £16,339 | **19,856** |
| **Wood** | £8,000 | £8,674 | £9,054 | £9,657 | £10,007 |

### 5.3.3 Other Related Impacts

Another related impact is the social aspect, which is not included in the decision support framework. Having considered both the environmental and economic impact of reusing and recycling C&D waste, there is a need to consider the social aspect in terms of acceptance and job creation. For the purpose or the study, only direct job creation potential obtained from waste systems was considered as opposed to other related impacts on reuse and recycling of C&D waste. Results of the short questionnaire, sent to some stakeholders:

- 2 Construction Workers,
- 2 Project Managers

- 2 Contractors (waste specialists)

Stakeholders are considered in relation to their views and opinion on employment potential in waste management system was used to determine other related impacts. The role of key stakeholders is previously discussed in the methodology chapter. Analysis of questionnaire feedback was done using cross tabulation and Likert scale data. Likert scale data is a bipolar scaling method, measuring either positive or negative response to a statement using even-point scale (Sullivan and Artino, 2013).

Coding system is used to analyse the questionnaire feedback. For question 1, the level of importance for salvaging/reuse, recycling, and waste disposal is established by Likert scale. Not Important = 1 point, Slightly Important = 2 points, Moderately Important = 3 points, Very Important = 4 points, Extremely Important = 5 points. A screen shot of the impact questionnaire sample is given in Appendix 5. For *salvaging/reuse* option *(n=6)* only 4 respondents agreed that the option is *Very Important* (i.e. 4*4 points =16) and 2 respondents believed that salvaging/reuse option is *Extremely Important* (i.e. 2*5 points =10). Therefore, the **Total points = 26** with an average of **26/6 = 4.3.** For *recycling* option *(n=6)* only 6 respondents agreed that recycling option is *Extremely Important* (i.e. 6*5 points =30).

**Total points** for response for recycling is 30 with an average of **30/6 = 5.** For *waste disposal to landfill* option *(n=4)*, 2 respondents agreed that recycling option is *Not Important* (i.e. 2*1 points =2) and 2 respondents believed that the option is *Slightly Important* (i.e. 2* 2 points =4). **Total points** for response for waste disposal is 6 with an average of **6/4 = 1.5.** By converting data to a single number as shown in Table 43 make it easy to draw comparisons and contrasts across the different groups. At the same time, the total number of respondents in each group is reported. From this outcome, recycling option is considered to be extremely important since it has the highest level of satisfaction.

**Table 43: Questionnaire feedback on policy options and level of satisfaction**

| Policy Options | Satisfaction |
|---|---|
| Salvaging/reuse *(n=6)* | 4.3 |
| Recycling *(n=6)* | 5 |
| Waste Disposal at Landfill *(n=4)* | 1.5 |

In question 2, the researcher asked participants to rate their level of agreement to impact categories for managing C&D waste on a 5-point Likert-type scale where Strongly disagree = 1 point, Disagree somewhat= 2 points, Neither agree or disagree = 3 points, Agree somewhat = 4 points, Strongly agree = 5 points. For *economic impact* category *(n=6)* only 4 respondents '*neither agree nor disagree'* on the economic impact of managing C&D waste (i.e. 4*3 points =12) and 2 respondents somewhat agreed that economic impact plays a major role in effective management (i.e. 2*4 points =8). Therefore, the **Total points = 20** with an average of **20/6 = 3.3.** For *environmental impact* category *(n=6)* only 3 respondents somewhat agreed that environmental impact plays a key role in the effective management of C&D waste (i.e. 3*4 points =12), whilst 3 disagree somewhat on environmental impact as a major factor (i.e. 3*2 points =6). **Total points = 18** with an average of **18/6 = 3.**

For *social Impact* category (n=6) all 5 respondents strongly agreed on social impact as a major key factor to be considered when managing C&D waste (i.e. social acceptance an job creation potential) (i.e. 6*5 points =30) and only 1 respondents disagree somewhat on the social impact (i.e. 1*2 points =2). **Total points = 32** with an average of **32/6 = 5.3.** Finally, the *political impact* category *(n=6)* was assessed. Survey result shows that 4 respondents agree somewhat (i.e. 4*4 points =16) on social impact as a major factor whilst only 1 respondent strongly agreed (i.e. 1*5 points =5) **Total points = 21** with an average of 2**1/6 = 3.5.** From Table 44, one can conclude with the small sample data that there are other related impact area affect effective management of C&D waste. Both social and political impact categories are new categories that required future extensive research as '*social acceptance of waste management policy and job creation potential*' (i.e. sensitive attributes of social impact) are now emerging factors that can be considered from the benefits derived from reusing and recycling operations.

**Table 44: Questionnaire feedback on impact categories and level of agreement**

| **Impact Categories** | **Agreement** |
|---|---|
| *Economic (n=6)* | 3.3 |
| *Environmental (n=6)* | 3 |
| *Social (n=6)* | 5.3 |
| Political (n=6) | 3.5 |

The third and fourth questions focused on the significance of waste management training. Feedback received shows that all six participants have had a varieties of training in waste management and they all agreed that there waste management requires more training. Although, the last two questions is not related to the theme of the sub-section but it helps the research to understand the importance of training and research development within the context of managing C&D waste.

## 5.5 Decision Analysis Results

The final stage of the decision-support framework is the decision analysis focused on analysing decision procedures for decision makers. The aim of this stage is to provide results of policy alternatives based on the criteria set to fulfil the overall study goal and objectives. The framework encouraged a decision hierarchy of the different policy alternatives to be established, as shown in Figure 24. The decision hierarchy was used as the foundation for the decision process and covers two key phases.

The first phase of the decision process is the development of the amalgamated impact support for decision makers. This model was developed to ensure that decisions could be established, with a deeper knowledge of related impact measures. The second phase of the decision process collected responses from questionnaires sent to decision makers to solicit input into the three phases of the Analytical Hierarchical Process (AHP), as developed in the decision support framework. The AHP provides weight to goals and objectives, alternatives and criteria, as demonstrated in Figure 24.

The perception on different preferences exhibited by the decision makers in rela to various policy alternatives, the criterion set, the goals and objectives established for the economic and environmental impact of reusing and recycling building waste was captured. Finally, the concluding step within the framework relies on the collection of the results into a definite ranking of different policy alternatives.

### 5.5.1 Pair Comparisons

The decision hierarchy, established in Figure 24, is a key aspect of the decision process as formulated in the established decision-support framework. Thus, the hierarchy is constructed with four key elements: alternatives, criteria, objectives, and goals. Six alternatives were chosen and then evaluated against the six impact criteria. Each criterion depicts respective goals and objectives (See Figures 45 & 46). Therefore, the goals and objectives are matched with individual criteria and respective policy alternatives. However, the alternatives selected are, 2, 5, 6, 7, 8 and 10 (Case Study 1) and 1, 3, 4, 8, 9 and 10 (Case Study 2). Each alternative selected indicated auspicious results in the criteria set.

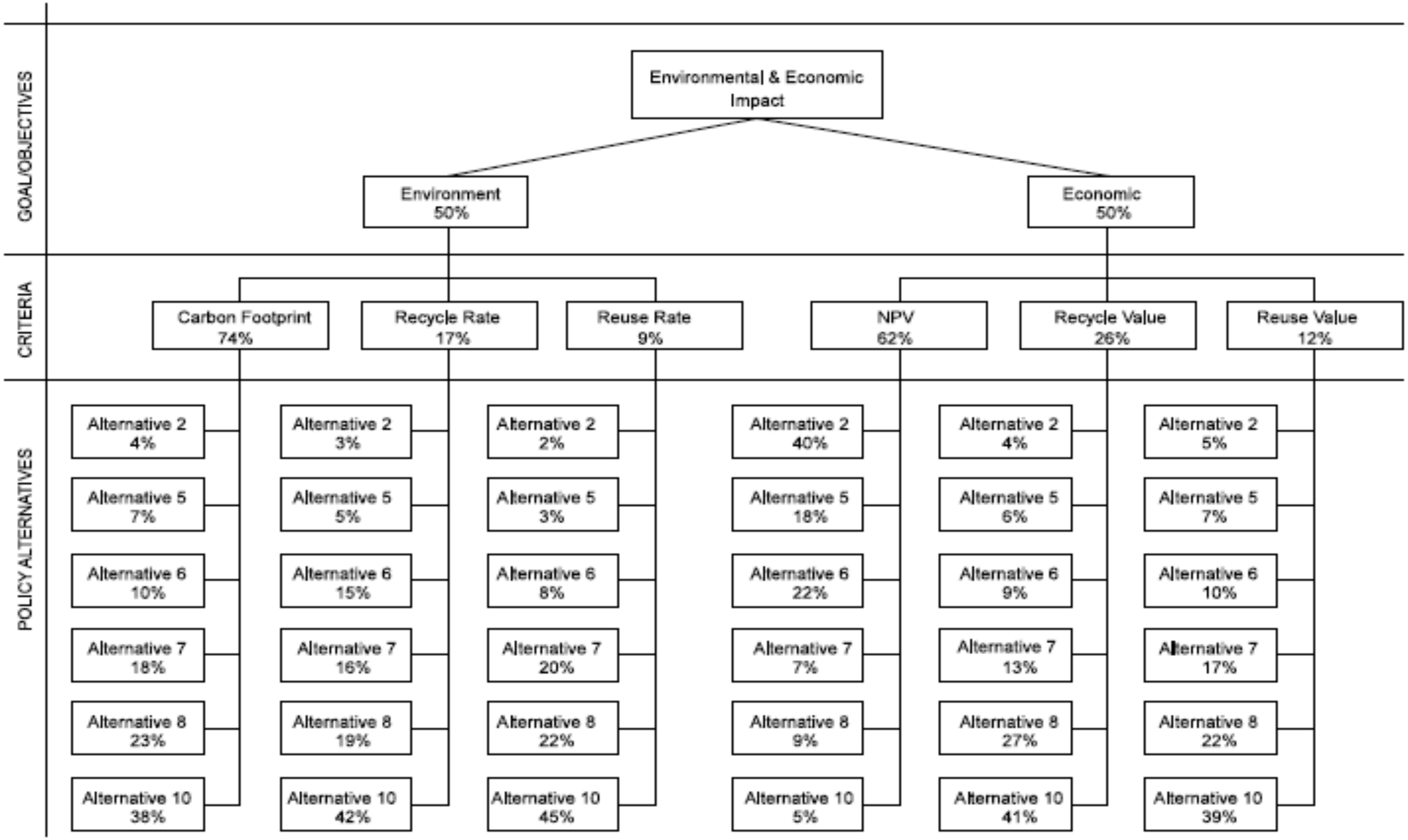


Figure 45: Decision process Hierarchy and relative results - Case study 1

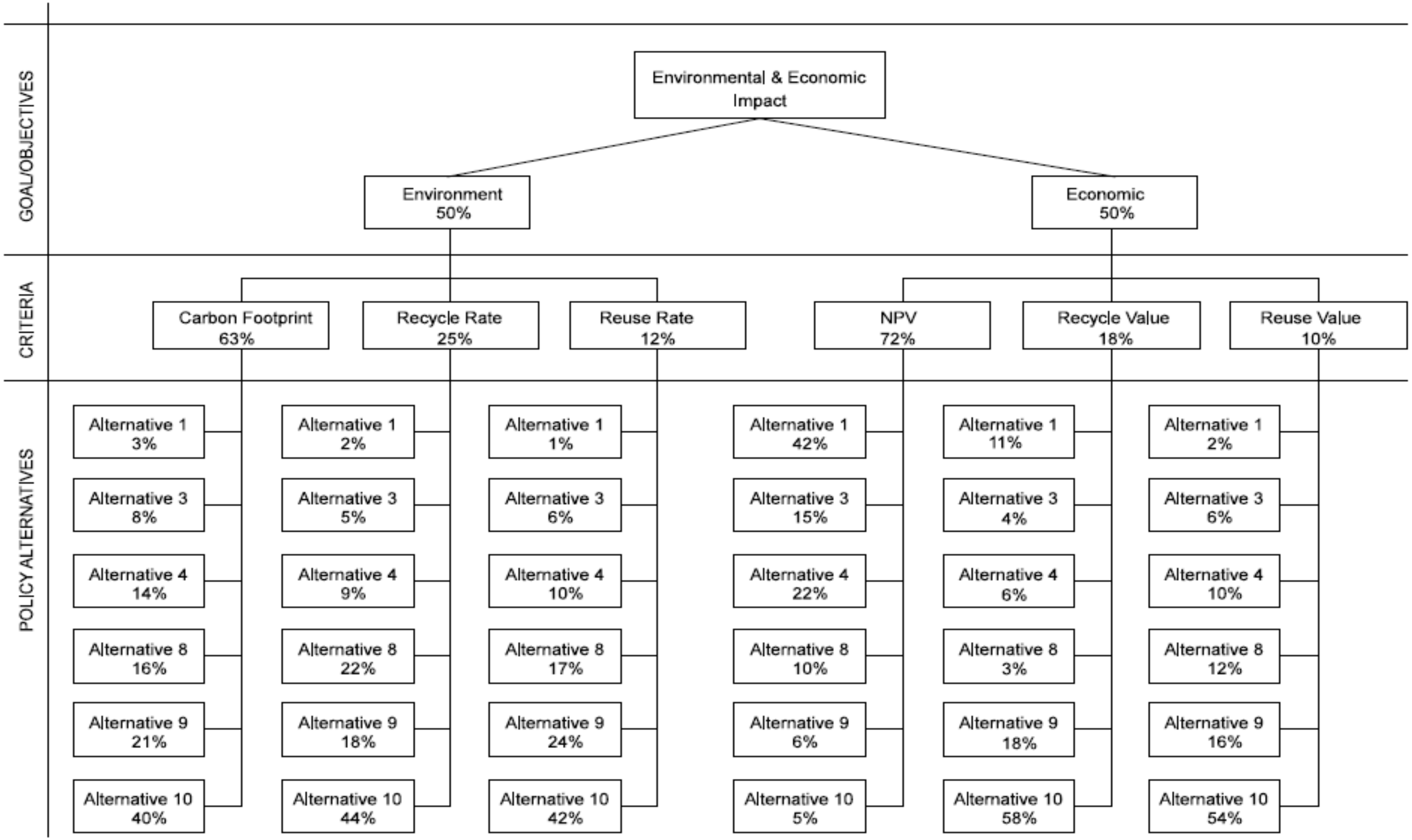
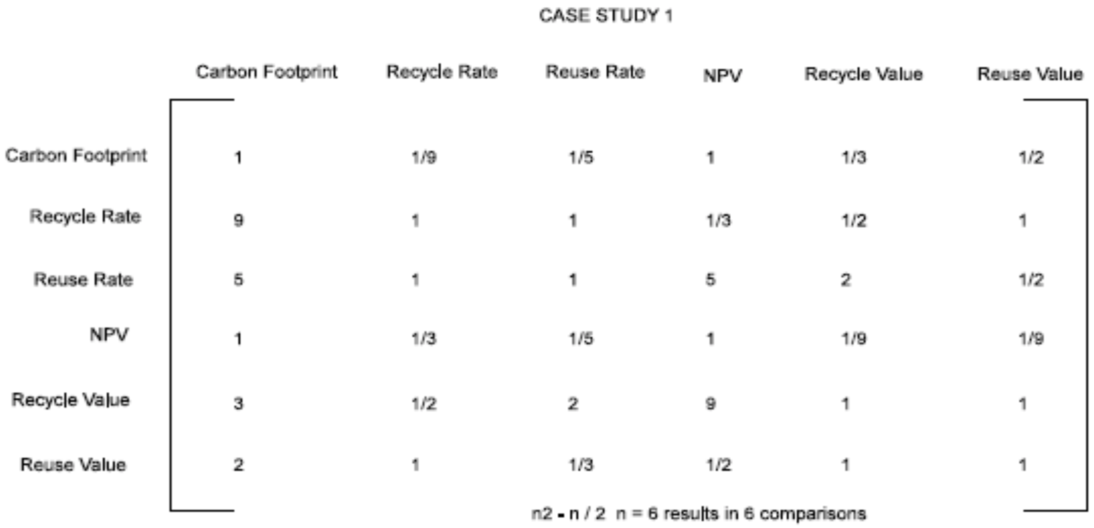


Figure 46: Decision process Hierarchy and relative results - Case study 2

### 5.5.1.1 Discussion of Decision Process Hierarchy Results

The C&D waste problems have been considered as part of the decision-making process, as the pairwise comparisons are used in such a way that the AHP model can evaluate identified policy alternatives. An important part of the decision process is to accomplish steps such as: stating the objective (i.e. economic and environment benefits), defining the criteria (i.e. carbon footprint, recycle rate, reuse rate, NPV, recycle value, reuse value), and finally choosing the policy alternatives (i.e. 2, 5, 6, 7, 8 and 10 [Case Study 1] and 1, 3, 4, 8, 9 and 10 [Case Study 2]. Figures 45 and 46 illustrate the decomposition of problems into a hierarchy of criteria and alternatives. The information is then synthesized in order to determine relative rankings of alternatives as shown in in Figures 45 and 46. Informed judgments with the help of decision-makers were used to derive weights and priorities.

The value of the pairwise comparisons in the AHP model is determined according to the scale introduced by Satty (1980), as illustrated in Table 11. According to this scale, the available values for the pairwise comparisons are members of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9} (See Table 11). In this scale, '1' has equal importance to the two objectives, '3' has moderate importance, '5' has strong importance, '7' has very strong or demonstrated importance, and '9' has extreme importance. The pairwise comparisons are applied to the two case studies in order to determine the relative importance of one criterion over another. Figure 47 shows the judgment matrix used to determine the relative importance of each criterion, where reasonable assumptions are made. The important question is how to move this judgment matrix to ranking criteria.



CASE STUDY 1

| | Carbon Footprint | Recycle Rate | Reuse Rate | NPV | Recycle Value | Reuse Value |
|---|---|---|---|---|---|---|
| Carbon Footprint | 1 | 1/9 | 1/5 | 1 | 1/3 | 1/2 |
| Recycle Rate | 9 | 1 | 1 | 1/3 | 1/2 | 1 |
| Reuse Rate | 5 | 1 | 1 | 5 | 2 | 1/2 |
| NPV | 1 | 1/3 | 1/5 | 1 | 1/9 | 1/9 |
| Recycle Value | 3 | 1/2 | 2 | 9 | 1 | 1 |
| Reuse Value | 2 | 1 | 1/3 | 1/2 | 1 | 1 |

n2 - n / 2 n = 6 results in 6 comparisons

Figure 47: Pairwise Comparisons - Determining the relative importance for Case study 1

CASE STUDY 2

$$\begin{array}{lcccccc}
 & \text{Carbon Footprint} & \text{Recycle Rate} & \text{Reuse Rate} & \text{NPV} & \text{Recycle Value} & \text{Reuse Value} \\
\text{Carbon Footprint} & 1 & 1/2 & 1/3 & 1 & 1 & 1/2 \\
\text{Recycle Rate} & 2 & 1 & 1/2 & 1/4 & 1/5 & 1 \\
\text{Reuse Rate} & 3 & 1/4 & 1 & 3 & 2 & 1/2 \\
\text{NPV} & 1 & 2 & 3 & 1 & 1/2 & 1/9 \\
\text{Recycle Value} & 1 & 5 & 2 & 9 & 1 & 1 \\
\text{Reuse Value} & 2 & 5 & 5 & 2 & 1 & 1
\end{array}$$

n2 - n / 2 n = 6 results in 6 comparisons

Figure 48: Pairwise Comparisons - Determining the relative importance for Case study 2

The next step is to evaluate the relative importance implied by comparisons, which can be determined by the principal *eigenvector* calculation (see screen shot of AHP model estimate in Appendix 6). In order to solve for the *eigenvector* (as demonstrated in Appendix 6), a short computation obtains the ranking used to raise the pairwise matrix to powers that are successively squared each time. The next step is the summation of the row, which is then normalized. Finally, the estimate step is instructed to stop when the difference between these sums in two consecutive calculations is smaller than a prescribed value.

A number of decision-making methods are used to determine the relative importance, or weight, of the alternatives in terms of each criterion involved in a given decision-making problem. Pairwise comparisons are used to determine the relative importance of each policy alternative in terms of each criterion. In this approach, the decision-maker has to choose an answer among selected discrete choices. Consequently, each choice is a linguistic phrase. Examples of such linguistic phrases are: '*Carbon Footprint is more important than Recycle Rate*', or '*Carbon Footprint is of the same importance as Recycle Rate'*. (See appendix 6 for relative importance scale).

The main problem with pairwise comparisons is how to quantify the linguistic choices made by the decision-maker during the evaluation. All the methods, which use the pairwise comparisons, approach eventually express the qualitative answers of a decision-maker in terms of some number, which are most often rations of integers. For this research, decision judgments are considered using a judgment matrix, where derived scales are used.

Note: The derived scale based on the judgments for Case study 1 is the matrix is:

0.74 0.17 0.09 0.62 0.26 0.12

With a consistency ratio (CR) of 0.118

The derived scale based on the judgments for Case study 2 is the matrix is:

0.63 0.25 0.12 0.72 0.18 0.10

With a consistency ratio (CR) of 0.185

The priorities, (obtained in exact form by raising the matrix to large powers, summing each row, and dividing each by the total sum of all the rows, or approximately by adding each row of the matrix and dividing by their total) are indicated at the bottom of Figure 47 and Figure 48, along with the true values expressed in relative form by dividing the relative importance of criteria by the sum of the relative importance of the selected criteria. The calculated *eigenvector* provides the relative ranking of all six criteria as shown in the derived scale.

Carbon Footprint is the most important criterion for Case study 1 & 2, followed by Recycling Rate, which is the second most important criterion under the environmental objective. Net Present Value (NPV) is the most important criterion, whilst Recycling Value is second most important. Figures 45 and 46 compile the hierarchical tree, which decomposes the central objectives into individual criteria. Decision-makers used judgments to determine the ranking of the criteria, as discussed in section 5.5.1.3. The significance of selected criteria was discussed, as there were pairwise comparisons against the outlined objectives.

Using pairwise comparisons, the relative importance of one criterion over another was expressed in ranking scores ranging from 1 to 9. In Figures 45 and 46, alternatives (5, 6) and (3, 4) are considered as intermediaries between criteria. More realistically, alternatives (7, 8, 10) and (8, 9, 10) were considered due to the positive results in relation to the environmental benefit in Case studies 1 and 2. From the study, however, it is noted that Carbon Footprint, Recycle Rate and Reuse Rate gave ranges of high to lower rates respectively.

### 5.5.1.2 Stage 1 – Objectives vs. Goal

Assessing the two central objectives, such as environmental and economic impacts of recycling and use of C&D waste, a pairwise comparison has been undertaken. The outcome leads to the comparisons needed to complete the decision support system. Table 45 shows the results of alternatives selected by respondents based on individual criterion. The weights assigned to the criteria in relation to each objective will be used as a deciding parameter in the selection process, as well as ranking of specific policy alternatives.

The pairwise comparison is to be completed by accounting for the derived scale based on the judgements and the established Consistency Ratio (CR); however, this was estimated as 0.0%, as shown in Table 45. Thus, the results show that through the early phase of the analysis, decision makers support both of the two objectives (i.e. environmental and economic impact) as equal determinants for reusing and recycling C&D waste.

**Table 45: Results of stage 1 (goal and objectives) and alternative pairwise comparison**

| Environmental and Economic Benefits | | |
|---|---|---|
| **Goal/Objective** | **Ranking %** | **Consistency Ratio (CR)** |
| Environment | 50% | 0.00% |
| Economic | 50% | |

### 5.5.1.3 Stage 2 – Criteria vs. Objectives

Stage 2 involved evaluating the significance of the selected criteria, which is measured against the objectives. The comparison of the two central objectives is measured against the criteria and the investigation of two straightforward pairwise comparisons is conducted. Each objective is attached to three criteria, as illustrated in Figures 44 and 45. It is clearly shown that the decision makers ranked carbon footprint, recycle, and reuse rates as postulated in Tables 46 and 47. Thus, the rankings of the criteria indicate consolidated preferences for the carbon footprint.

In Case Study 1, the weighted score for carbon footprint is seen at 74%, indicating a very strong relationship as compared to the recycling rate (17%) and reuse rate (9%) for a given alternative. For Case Study 2, weighted score for carbon footprint is observed as 63% showing a moderately strong relationship as compared to the recycling rate (25%) and reuse rate (12%) for individual alternatives. In an economic viewpoint the values for NPV, recycle and reuse were tabulated in Table 48 and 49. In Table 48, the highest criterion is selected in terms of NPV.

However, preference of about 62% is provided for NPV, showing a strong relationship in choices made by decision makers. Also, both the recycle and reuse values are noted to be 26% and 12% respectively, as shown in Table 48. In Table 49, a higher NPV of about 72% was noted for Case Study 2 with both the recycle and reuse values observed as 18% and 10%, respectively. Thus, the NPV gives an overall clarity of value of policy alternatives, which was more essential to decision makers.

**Table 46: Results for Environment criteria and alternative - Case study 1**

| Environment | |
|---|---|
| **Criteria** | **Ranking %** |
| Carbon Footprint | 74% |
| Recycling Rate | 17% |
| Reuse Rate | 9% |

**Table 47: Results for Environment criteria and alternative - Case study 2**

| Environment | |
|---|---|
| **Criteria** | **Ranking %** |
| Carbon Footprint | 63% |
| Recycling Rate | 25% |
| Reuse Rate | 12% |

**Table 48: Results for economic criteria and alternatives - Case study 1**

| **Economic** | |
|---|---|
| **Criteria** | **Ranking %** |
| NPV | 62% |
| Recycling Value | 26% |
| Reuse Value | 12% |

**Table 49: Results for economic criteria and alternatives - Case study 2**

| **Economic** | |
|---|---|
| **Criteria** | **Ranking %** |
| NPV | 72% |
| Recycling Value | 18% |
| Reuse Value | 10% |

### 5.5.1.4 Stage 3 – Alternatives vs. Criteria

The established six alternatives were compared discretely against each specific criterion for the two case studies. The results for individual criterion were outlined in Tables 50 and 51 with respective CR measures of about 10% to 11% being estimated. The results for the environmental assessment evaluation (i.e. Case study 1 & 2) are outlined on Tables 48 and 49, using rankings and criteria such as carbon footprint, recycling and reuse rates, respectively. The results in Tables 46 and 47 show a strong preference from decision makers in terms of carbon footprint for alternatives 7, 8, and 10 (Case Study 1) and 8, 9, and 10 (Case Study 2). However, alternatives 2, 5 and 6 (Case Study 1) and 1, 3 and 4 (Case Study 2) were considered to be least accepted alternatives for carbon footprint.

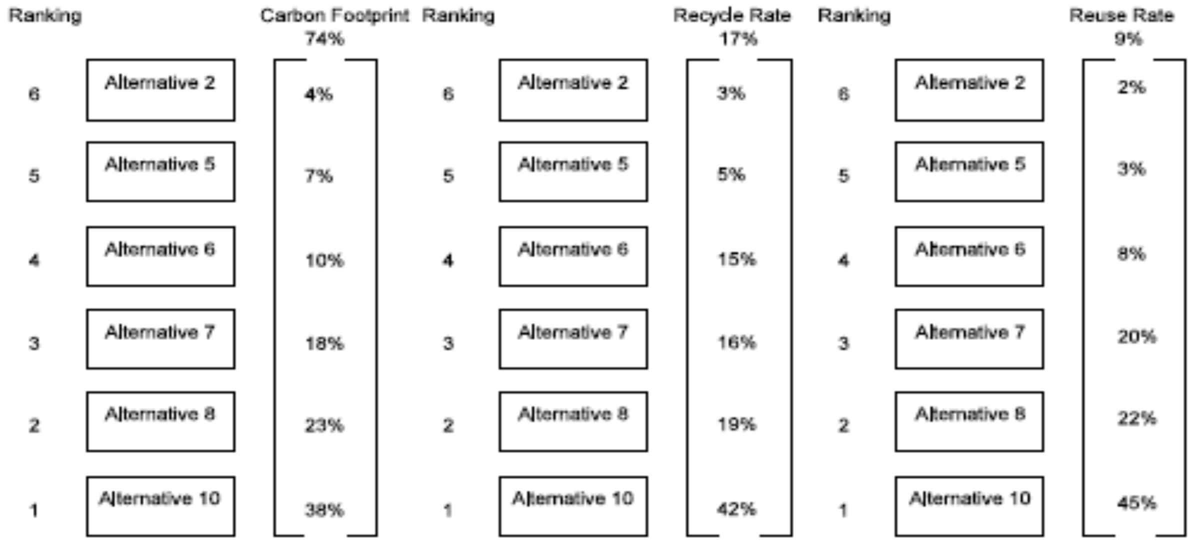


Figure 49: Ranking for Criteria under Environmental objective - Case study 1

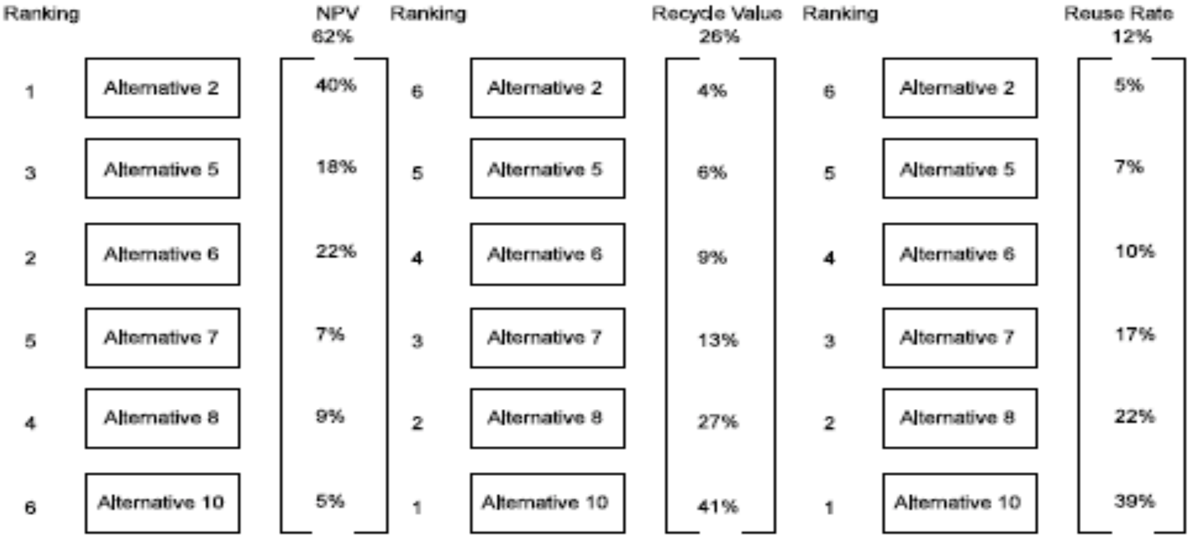


Figure 50: Ranking for Criteria under Economic objective - Case study 1

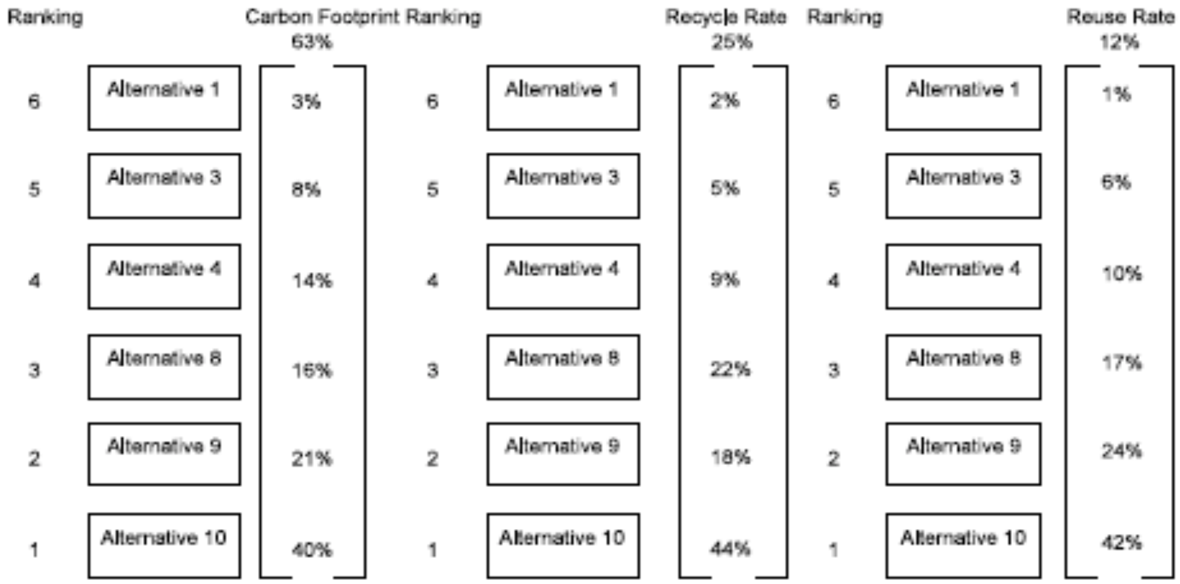


Figure 51: Ranking for Criteria under Environmental objective - Case study 2

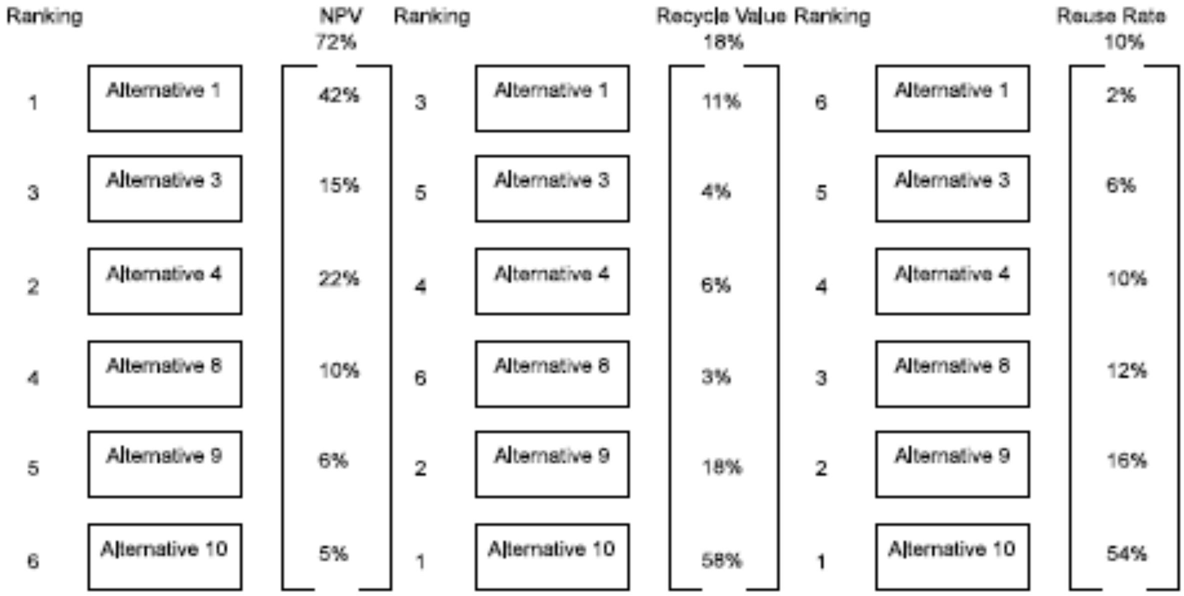


Figure 52: Ranking for Criteria under Economic objective - Case study 2

In Tables 46 and 47, alternative 10 shows the lowest value of carbon footprint and was selected as the most desirable alternative as perceived by decision makers between the two case studies. An evaluation of recycling and reuse rates followed the carbon footprint measure where selection favours alternative 7, 8 and 10. The efficiency of both recycling and reuse operations shows a high value for individual alternatives. Thus, alternative 10 provides an outcome, which is significantly more favourable as compared to alternative 2 and alternative 8. The economic measure was determined for the evaluation of criteria and was compared against all six alternatives. The decision result is illustrated in Tables 48 and 49 with NPV alternative results significantly represented and favourable for alternative 2 and 10.

A desired ranking of 41% (38% in Table 50) was recorded for NPV in the decision hierarchy model illustrated in Figure 45. This Figure shows a higher performance within the waste system. However, alternative 6 was observed as the second highest for NPV in the ranking table as it has 22% from Figure 45 and Table 48 as an outcome of responses of decision makers and preference level measure. Thus, alternative 8 and 10 have ranking percentage scores between 6% and 9%, respectively.

**Table 50: Results for the environmental criteria and alternatives for stage 3 - Case study 1**

| | Carbon Footprint | | Recycle Rate | | Reuse Rate | |
|---|---|---|---|---|---|---|
| **Option** | **Ranking (%)** | **CR** | | **CR** | **Ranking(%)** | **CR** |
| 2 | 4 | **5.21%** | 3 | **9.83%** | 2 | **9.95%** |
| 5 | 7 | | 5 | | 3 | |
| 6 | 10 | | 13 | | 10 | |
| 7 | 17 | | 15 | | 21 | |
| 8 | 22 | | 25 | | 26 | |
| 10 | **40** | | **39** | | **38** | |

**Table 51: Results for the environmental criteria and alternatives for stage 3 – Case study 2**

| | Carbon Footprint | | Recycle Rate | | Reuse Rate | |
|---|---|---|---|---|---|---|
| **Alternative** | **Ranking (%)** | **CR** | | **CR** | **Ranking(%)** | **CR** |
| 1 | 1 | **6.06%** | 3 | **10.05%** | 2 | **10.65%** |
| 3 | 6 | | 8 | | 5 | |
| 4 | 10 | | 14 | | 9 | |
| 8 | 17 | | 16 | | 22 | |
| 9 | 24 | | 21 | | 18 | |
| 10 | **42** | | **40** | | **44** | |

**Table 52: Results for the economic criteria and alternatives – Case study 1**

| | NPV | | Recycle Value | | Reuse Value | |
|---|---|---|---|---|---|---|
| **Alternative** | **Ranking (%)** | **CR** | | **CR** | **Ranking(%)** | **CR** |
| 2 | **38** | **2.21%** | 4 | **3.86%** | 5 | **3.68%** |
| 5 | 18 | | 6 | | 7 | |
| 6 | 22 | | 9 | | 10 | |
| 7 | 7 | | 16 | | 19 | |
| 8 | 6 | | 28 | | 23 | |
| 10 | 6 | | **37** | | **36** | |

Table 53: Results for the economic criteria and alternatives – Case study 2

| | NPV | | Recycle Value | | Reuse Value | |
|---|---|---|---|---|---|---|
| **Alternative** | **Ranking (%)** | **CR** | | **CR** | **Ranking (%)** | **CR** |
| 1 | **42** | **4.68%** | 11 | **5.89%** | 2 | **3.68%** |
| 3 | 15 | | 4 | | 6 | |
| 4 | 22 | | 6 | | 10 | |
| 8 | 10 | | 3 | | 12 | |
| 9 | 6 | | 18 | | 16 | |
| 10 | 5 | | **58** | | **54** | |

The recycling and reuse results from an LCA perspective indicated that alternative 10 for both case studies was ranked to be the most suitable alternative due to linear correlation observed during estimation. However, the ranking favourability and the results indicated a similar trend as alternatives 8 and 10 are greatly ranked alternatives (28% and 37% in recycle value and 23% and 36% in the reuse value) in Case Study 1 and 8, 9 and 10 for Case Study 2. In summary, the analytic hierarchy process provides a logical framework to determine the benefits of each policy alternative. Alternative 8 and 10 is the highest ranked policy alternative considered by decision makers.

### 5.5.2 Sensitivity Analysis

A sensitivity analysis is carried out for the study under the AHP. This was carried out, by explaining the variation in the weights apportioned to the objectives. The main goal of sensitivity analysis is to gain insight into which assumptions are critical (i.e. which assumptions affect choices made by decision makers). Thus, the weights were readjusted by assigning a single objective to a score of 5, resulting in a ranking of 85.5% to environmental impact and 14.5% to the economic impact, if there is need to be biased (see Table 15). Therefore, the sensitivity analysis for the case study will be the transition in weights of the objectives of environmental and economic benefits.

The transition of weights will be shown in policies, which reflect preferences for one objective. The sensitivity analysis further shows a bias towards one objective. In cases where the AHP model is biased towards economic impact, a weight of 3 will be observed as the environmental impact weights equal to 1. First, the environmental objective was considered and biased against the economic objectives. The economic objectives were selected and observed to have equal importance with a score of 1. The outcome indicates that alternative 10 is favourable as compared to alternative 2, with a 5% margin greater for the two case studies. This implies that the greater focus on the environment requires the performance of carbon footprint criteria, which determines the preferred policy alternatives.

In light if this, alternative 10 for both case studies tends to outperform other alternatives in terms of reducing greenhouse gas emissions through recycling and reusing C&D waste. The importance of deciding on the most appropriate policy alternatives can be decided through the sensitivity analysis. Finally, the sensitivity analysis provides a strong relationship with alternative 10 in relation to the views and opinions of decision makers who consider activities from the two case studies. The preference on alternative 10 simply gives an overall perception for decision makers as they fully support recycling and reuse of C&D waste, and also support the improvement of both environmental and economic objectives.

### 5.5.3 Making the right Decision

The results of the pairwise comparisons can be consolidated with regards to the results of the alternatives, criteria and objectives developed in the decision support framework, and these were directly obtained for the two case studies. Figures 44 and 45 shows the views of decision makers that supported the framework. The final results for the AHP decision process for the case study application are discussed in the subsection below.

#### 5.5.3.1 Results of AHP Decision Process

The response of the questionnaire sent to decision makers gave an insight into making the right decision. Six respondents completed the questionnaire on types of policy alternatives preferred. From Case Study 1, alternatives 2, 5, 6, 7, 8 and 10 were selected and views and opinions were solicited from decision makers’ standpoints. All six decision-makers (i.e. key stakeholders identified in section 5.3.3) agreed that policy alternative 10 is the most preferable within the selection, however, only two of these stakeholders believed that policy alternatives 2, 5, 6, 7 and 8 are more preferable. On the other hand, 1, 3, 4, 8, 9, and 10 were considered for opinions of decision makers in making preferred choice of policy alternatives for Case Study 2.

All respondents (i.e. questionnaire survey results) to the questions believed that the selected policy alternatives are favourable to meet all environmental and economic impacts of recycling and reusing C&D waste. Alternative 10 was agreed to give the best performance for the two case studies. In responding to the first scenario as shown in the questionnaire distributed to respondents (key stakeholders) it was found that policy alternative 8 and 10 is the most preferred for Case study 1. However, two of the respondents gave a different feedback in selecting other alternatives within the framework on Case study 2.

The AHP model shown in Figures 45 and 46 shows the results of the survey on the first stage of the decision-support framework. This shows that alternatives 8 and 10 are favoured in Case Study 1 and in Case Study 2 only 1, 4, 9 and 10 are the most favoured. The final ranking for decision support is observed and commented on. This information was gathered from the response to the questionnaire distributed to decision makers in relation to economic and environmental objectives. The economic impact measure considered the NPV value for alternatives 2, 5, 6, 7, 8, and 10 (Case Study 1) and 1, 4, 9 and 10 (Case Study 2). For Case study 1 all six respondents agreed that economic impact often affect the policy alternatives 2, 5, 6, 7, 8, and 10 in relation to the extent of NPV values. In Case study 2, all six respondents also agreed that policy alternatives 1, 3, 4, 8, 9, and 10 can be greatly influenced by economic impact by considering the values of NPV.

Significantly, the decision results for NPV supports alternative 2 and 5 in Case Study 1 and favoured 3 and 4 in Case Study 2. Thus, the economic performance of alternative 5 increases the ranking percentages as a result of environmental performance. Responses from the questions indicate that the least favoured is alternative 2 as all six respondents believed that policy does not favour high rate of C&D waste going to landfill. Considering the intermediaries such as alternative 5 and 6 the range of ranking percentage falling noticeably for both environmental and economic impact objectives. Finally, response rates from decision makers (respondents) support alternatives 8 and 10 as the highest favoured options on environmental and economic impact objectives for the two Case studies (See AHP model in Figures 44 and 45).

### 5.5.3.2 Decision Inconsistency

Whilst selecting policy alternatives 8 and 10 for Case study 1 and 1, 4, 9 and 10 for Case study 2, some inconsistencies were found with decision maker's preferences in terms of ranking for recycling and reuse rates. Some respondents disagreed with policy alternative for recycle and reuse values. To determine the decision maker's consistency checklist two steps were carried out as modelled in Equation 4, 5 and 6 where the consistency ratio (CR) were considered using Random Index (RI) to finalise the AHP model. Some decision maker's preferences are consider where CR>0.10 showing inconsistencies in the selection of various policy alternatives (See Tables 50, 51, 52 and 53).

## 5.6 Validation

The validation of the decision-support framework has been considered using two key aspects. The first aspect examines the validity of the developed framework with the intention to collect and interpret the environmental and economic benefits of recycling and reusing C&D waste. Tables 54 and 55 show the results of the sensitivity analysis and this will be represented for the framework validation. Response received from survey on policy alternative preferences for key objectives shows variation in the overall outcome. In Case study 1 total of 6 responses were received indicating that decision makers are biased toward economic objective, however majority feels that environment benefits are more importance than economic benefits for managing C&D waste. Alternative 10 is the most favourable alternative as a result of the survey outcome.

Table 54: The results from a sensitivity analysis - Case study 1

| | Biased towards objectives (Case study 1) | | |
|---|---|---|---|
| Policy alternatives | Environmental | Economic | Total Response |
| 2 | 1 | 1 | 2 |
| 5 | 2 | 1 | 3 |
| 6 | 3 | 1 | 4 |
| 7 | 2 | 2 | 4 |
| 8 | 3 | 3 | 6 |
| 10 (F) | 4 | 2 | 6 |

Table 55: The results from a sensitivity analysis - Case study 2

| | Biased towards objectives (Case study 2) | | |
|---|---|---|---|
| Policy alternatives | Environmental | Economic | Total Response |
| 1 | 1 | 0 | 1 |
| 3 | 0 | 2 | 2 |
| 4 | 1 | 1 | 1 |
| 8 | 2 | 2 | 4 |
| 9 | 2 | 3 | 5 |
| 10 (F) | 4 | 2 | 6 |

The sensitive analysis shows that alternative 10 for both case studies outperforms all other alternatives in terms of economic and environmental measure. However, other validation of the framework was determined by the responses from decision makers, which was used to determine the preferential level for different policy alternatives.

### 5.6.1 Framework Validation

The framework is developed to assist decision-making, based on the economic and environmental benefits of recycling and reusing C&D waste. To validate the current decision-support framework there is a need to look closely at the development of LCA and MCDA model. The framework firstly considered the LCA model in order to collect waste inventory data and later analysed this against associated impact measures. Secondly, the MCDA model was analysed with special attention to the AHP platform, using the AHP tool to deal with complex problems using pairwise comparisons based on judgements of decision makers to derive priority scales for various policy alternatives. The LCA model gave an overview of waste inventory results with a thorough investigation of individual processes. The end results were then stretched and impacts were estimated for the various policy alternatives developed. Conversely, the framework offered satisfactory impact results that could be reviewed and compared with different alternatives.

The validation of the decision making process marks the end process of the framework development with the central aim to expedite and help decision makers deciphering results and making consistent and realistic decisions. Thus, the framework was developed with the support of two project site managers of the two case studies. The studies, however, acknowledged the importance of consistency in decision-making processes, and this has led to consistent iterations incorporated in the AHP model in order to arrive at a consistent precise outcome. This is demonstrated in the results of the decision analysis in relation to the outcome of the Carbon footprint and NPV output for selected policy alternatives.

### 5.6.2 Result Validation

The result validation from Case Studies 1 and 2 involved two key steps. First, three key elements, such as life cycle mapping, inventory data gathering and impact analysis, are carefully considered. These key elements are presented to three anonymous site managers at the two Demolition and New Build projects. These individuals solicited their inputs and gave satisfactory responses on all selected policy alternatives and criteria set, as discussed in section 5.5.3.1. Second, AHP decision procedure is considered with the greater focus on the decision making process. This has relied strongly on the input of decision makers. Feedback from questionnaires have shown that positive responses to alternatives 8 and 10 (Case Study 1) and 8, 9 and 10 (Case Study 2) to outperform other policy alternatives, in terms of assessing the environmental and economic impact or recycling and reusing C&D waste. The response received from respondents helped provide consistency through ranking percentages. With the achievement of decision analysis, key findings and discussion was presented within the case study. The validation of results relates to the decision makers input and this has provided valuable and rich data on policy impact in terms of future potential in recycle and reuse of C&D waste. There is a need to organise and make decisions in relation to objectives and criteria set, however, there is a need for integration and structure of objectives against criteria set. The decision support framework is developed to assess the current policy impacts on recycling and reuse of C&D waste for future sustainable approach to waste management.

## 5.7 Summary

The two case studies analysed for the research are on the waste management system for the Demolition and New Build projects managed and executed by Global Construction Company (GCC) on two different projects (medium and small scale). The case studies targeted the impact that the Demolition and New Build projects have on the environment and the economic determinant of managing C&D waste by developing a decision support framework. The framework is developed in Chapter 4 and applied and finally validated in Chapter 5. Two impact categories were analysed and a decision support framework was developed and applied to the main case study. Defining the framework goals and scope within which it is developed and implemented completes the first phase of the decision support framework.

The second phase incorporates the inventory data analysis and the development of policy alternatives in order to measure it again individual criteria set. Within the LCA inventory analysis, six impact criteria were categorised from a policy standpoint, which allowed a careful examination of the measure of environmental and economic impact on recycling and reuse of building waste. The final stage of the decision support framework later applies AHP's decision procedure to the case study where input from decision makers were collected and ranked accordingly to established individual preferences. By applying the key aspect of the framework to a real-life project, one can validate the effectiveness of the decision support system by the valuable feedback gathered from decision makers and/or respondents. The success achieved from phase 1 of the framework has facilitated the validation process. The definition of goal and scope gave a direction to the input data and the development of the impact criteria set for appropriate comparisons.

However, the research has moved forward by validating the decision support framework through collecting responses from managers (decision makers on the two case studies) who work on the demolition projects by asking them about their views and opinions on different policy alternatives. Finally, outcomes supported Case Study 2 in terms of environmental and economic measures as significant amounts of carbon emissions were reduced due to the size of the project. However, the results of the policy alternatives, discussed by individuals, have been found satisfactory and it has given a consolidated outcome to justify the use of the two management tools LCA and AHP (i.e. key aspect of MCDA).

# CHAPTER 6: Discussion and Conclusions

## Chapter Aim:

The purpose of the chapter is to draw together the work presented in previous chapters and validate all central arguments, key findings, and discussion within the thesis. After reviewing the work done so far, the chapter further highlights the constraints and limitations of the study followed by concluding remarks and a reflection on the research question, hypothesis, and overall objectives. Finally, the academic contributions to enhancing the body of knowledge within C&D waste management are discussed.

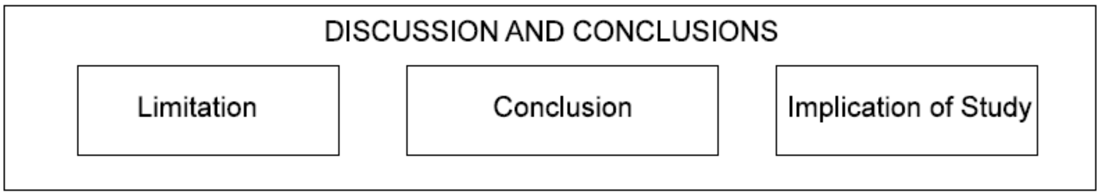


Figure 53: Discussion and Conclusions

## Chapter Objectives

- **Review** the work carried out in this thesis
- **Discuss** the constraints and limitations of the study
- **Draw** all strand of arguments together in the previous chapters and present a definite conclusion
- **Provide** valid answer to research questions and define how each objective is met.

## 6.1 Review of Work Done

Designing a decision-support model has been the top priority for most construction firms in the United Kingdom. The management of solid waste (MSW), however, requires complex decision-making processes. Thus, the selection of appropriate management tools may be limited in most cases. The decision-support models can help policy makers to select and design sustainable and cost-effective waste management systems. Chapter 1 introduces and gives a holistic view of the problem statement, hypothesis, and objective of the entire thesis.

Chapter 2 consists of the state of knowledge, which covers eight key sub-topics: waste and its definitions, C&D waste streams, sorting and management consideration, waste management hierarchy, roles of waste management, economic aspects of building waste material, waste management legislation, and policy implication, and the effects of the legislation. The focus is then shifted to reviewing available management tools presented in the third chapter. Thus, Chapter 3 is an extension of Chapter 2, which presents the theoretical foundation of the thesis, discussing waste management tools in relation to environment and economic measures, and the opportunities and limitations of LCA and MCDA tools.

Chapter 3 gives a direction to the development of the decision-support framework, which is fully constructed in Chapter 4. The discussion of the two key models such as LCA and AHP (selected aspects of the MCDA model) supports the policy decisions with regard to environmental and economic impact. Based on the conclusions drawn in chapter 3, the LCA and AHP model were selected as suitable tools that could be adopted to construct the decision-support framework. From the literature, LCA was found to be a suitable tool for generating effective inventory data, and is used to analyse the associated impact measure.

The LCA tool, however, lacks a decision-making platform for the framework and therefore a more integrated and complex problem-solving tool such as MCDA is considered to deal with decision conflicts often seen among design criteria in waste material selection, with the help of LCA input data. Thus, the policy framework created in Chapter 4 depicts an integrated tool that consults both the LCA and MCDA models. The integration of these two management tools on the basis of assessing the environmental and economic impact of recycling and reuse of C&D waste has helped the study to develop a realistic decision-support framework for decision makers.

Four phases were considered for the development of the framework. These stages assess goal and scope, LCA inventory data for the waste system, LCA impact categories, and

AHP (the decision analysis phase). Significantly, three stages were considered in that LCA inventory phase, and then two key aspects (environmental and economic) were considered in the impact categories section. The framework is developed to decide upon the environmental and economic benefits of the recycling and reuse of building waste. After the development of the decision-support framework, the study progresses by applying and validating the framework to two real-world case studies (Medium and Small-scale Demolition and New Build projects). The case studies were coordinated with the support of a Global Construction Company (GCC).

## 6.2 Constraints and Limitations

The study was undertaken as a contribution to sustainable development in waste management processes. It is important therefore to describe the context and resulting constraints placed on this study from its outset before results are presented. The constraints are presented as two separate issues. First, waste data collection from construction firms and waste specialists was limited by confidentiality issues and privacy. Second, the qualitative aspect of the research was not carried out due to confidentiality issues and inconsistencies in the scheduled time for intended participants. Therefore, the study relies on questionnaire responses from decision makers to rank different policy alternatives.

The limitations of the study are related to the integration of the two management tools LCA and MCDA. These are highlighted as follows:

- The type and nature of data gathered limits the type, nature, and scope of the analysis that can be carried out. Rich and high-quality data would ensure a much more realistic comparison between options.

- The data gathered for the study is location-specific. There might be variations in other local London districts, however, in terms of cost-saving on the recycling and reuse of building waste material as compared to virgin material, the study found that recycling and reuse of C&D waste in North London is more economically and environmentally viable than disposal at landfill.

- Both the environmental and economic impact of the recycling and reuse of C&D waste can be justified by the extent of waste management operations; knowledge relating to the application of environmental and economic benefits to waste management, however, lies within the experience of decision makers.

- A rethink on conventional waste management approaches limits the consideration of a more sustainable approach. Therefore, there is a need for more awareness of sustainable approaches to waste management on many construction sites. Here, the impact of decision-making for different policy alternatives is not yet considered.

- Key issues concerning the recycling and reuse of waste materials are limited to the unsustainable approach and organisational culture of most construction firms. Therefore, the information gathered for this study was constrained by the lack of full data justifying the economic and environmental benefits.

Thus, the limitations outlined above have given a direction for arriving at a definite conclusion; there is nevertheless a need to discuss some methodological issues within the current study.

### 6.2.1 Methodological Issues

The findings from the current study highlight both opportunities and limitations for using available management tools (LCA and MCDA) in developing the decision-support framework. Although Chapter 3 gives a valuable insight into the usefulness and effectiveness of using both LCA and MCDA individually, there are still some issues to be considered whilst evaluating applications of these two management tools.

According to Boufateh et al. (2011), MCDA provides a clear and transparent methodology for making decisions and also offers a formal way of combining information from disparate sources. The application of the AHP decision-making procedure has proved this to be true to some degree, but there is a need for personal judgement and experience to rank individual policy alternatives against individual criteria before conducting a pairwise comparison.

Another issue found with the AHP model (an aspect of MCDA model) is that the allocation of weights is subjective and often affects end results. A practical example is the end result of Alternatives 1, 2, 6, 8 and 10. Despite the fact that Alternative 1 is unfavourable as compared to Alternatives 8 or 10, other considerations for expert judging focus more closely on other similar policy alternatives within the decision-support framework.

Key findings on the use of the AHP decision analysis model relate to the complex nature of matching individual criteria with different policy alternatives in order to arrive at am end result that meets the goals and objectives of the framework. This supports Morrissey and Browne (2004), who argue that the MCDA technique can be very cumbersome and unwieldy. The researcher found this to be true whilst compiling all data, objectives, criteria, and alternatives to meet the overall goals of the study.

### 6.3 Implication of Study

The study has revealed the potentially huge economic and environmental benefits that could be obtained by reusing and recycling C&D waste. On the other hand, the study acknowledges the fact that *'recycling'* is thought to be a vital part of reducing the environmental impact of the construction industry. Thus, the reuse and recycling process uses energy and emits $C0_2$, which must be balanced against any cost and energy savings. For example, $C0_2$ is released when transporting waste from construction and demolition sites to reuse and/or recycling facilities, and energy is required to operate machinery that sorts and processes that waste.

The research examined reuse and recycling facilities and onsite activities, and found that over a six-month duration two Demolition and New Build projects (Case Studies 1 and 2) would likely produce around 16.5 (Case study 1) and 9.4 tonnes of $C0_2$ (Case study 2). This simply means that Medium-scale Demolition and New Build projects produce more $C0_2$ than Small-scale Demolition and New Build projects. There has been significant reduction of carbon emission for Case study 2 due to the recycling and reuse activities performed. Thus, through implementing more efficient management procedures, the two Demolition and New Build projects should prevent emissions of 3.4-6.2 tonnes over the same period. The results also predict that the project would use the equivalent of more than 1.4 tonnes of $C0_2$, originally produced, but would have the capability of conserving about 80% of that amount.

The researcher also noted that the economic and environmental benefits would only be seen if output waste material sent from the facility and onsite activities were effectively sorted and efficiently used within the production of new materials. The implication of study in this regard, however, is the production of new products through the opportunity of recycling processes. The study also indicates that a reduction in the amount of waste produced according to policy alternatives would create significant environmental benefits in relation to transporting waste materials, as fewer trips would be required. The study further suggests that transport to and from the processing center and on- and off-site will account for more than half of $C0_2$ emissions amassed by the Demolition and New Build project, and that targeting a reduction of regular trips would make a considerable difference in minimising the economic and environmental impact.

The study suggests that recycled products such as concrete, plastic, and paper continue to be considered by local contractors as better options in road paving and civil works, landfilling for foundation pads, and general construction. The study also shows that the cost of the reuse and recycling of C&D waste is lower than the cost of disposal by evaluating the most realistic policy alternatives as illustrated in the case study decision-support application. The study is location-specific, however, as there might be variation in recycling and disposal in other London districts compared to North London. Another key finding of the study is that source separation of C&D waste on- and off-site has the following advantages: high recycling and reuse rates; lower recycling costs, revenue paid for some materials; cleaner, safer work sites.

A few negative observations include the issue of multiple containers, skips, and wheelie bins on construction site, workers employed to separate materials for recycling on-site and more complex logistics. Aside from the negative aspects of recycling processes, the positive outcomes of the recycling and reuse of C&D waste have shown its reliability through the economic and environmental impact assessment carried out in the research. Thus, this study adds to existing knowledge by assessing the economic and environmental impact of the reuse and recycling C&D waste, and further suggests that with effective planning and development of a realistic waste management plan, many construction sites across the country will achieve the full potential of the 3R concept (i.e. reduce, reuse and recycle), and come close to attaining ultimate ‘zero waste’.

## 6.4 Academic Contribution and Benefit of the Study

This research relies strongly on the analysis of data collected directly from real-life case studies on medium and small-scale Demolition and New Build projects. Individual names and detailed company information are excluded from the study due to confidentiality and privacy considerations. Thus, this study contributes to a greater knowledge of the environmental and economic impact of C&D waste streams, specifically evaluating the significant benefits of the recycling and reuse of C&D waste and investigating how this can be effectively managed in the future. This research is presented as contributing to existing knowledge, giving a new focus to effective management of C&D waste in areas of economic and environmental benefits.

A few research studies (Bilec, et al., 2012; Srour, et al., 2012; Achillas, et al., 2013; Liu and Wang, 2013; de-Beer 2013) have performed similar research over the years.

Interestingly, only a few of these studies combine the LCA and MCDA models, weighing alternatives by considering two case studies (medium and small-scale projects). The research conducted in this thesis provides a new approach to the effective management of C&D waste. The study found that a significant reduction of $C0_2$ could be achieved in small-scale Demolition and New Build projects as compared to medium and/or large-scale projects. The implications of these findings are not insignificant, due to the volume of demolition and construction works to be carried out. The first case study shows that a moderate reduction in the amount of $C0_2$ emitted can be achieved, and that there is an economic benefit in reusing and recycling C&D waste.

The uniqueness of the current research lies in the thorough assessment of waste flow systems through the LCA model with the proposed LCA mapping to track the data input and impact category assessment. The research adopts the AHP model (an aspect of the MCDA model) to help justify the best policy alternatives made by decision makers in terms of the effective management of C&D waste. Key findings for recycled products (i.e. concrete, plastic, and paper) are discussed, as new observations from field case studies show that these three C&D waste materials often attract local contractors. Interestingly, this outcome also supports previous related work (i.e. Kijak and Moy, 2008; Zhao, et al., Tam, 2011) which argued that concrete, plastic, and paper are better options for contractors in areas of major construction works.

Therefore, this evidence leads to the conclusion that the effective management of C&D waste has huge economic and environmental benefits. This study was the first in the United Kingdom to assess both the environmental and economic benefits of C&D waste management by considering a combination approach using LCA and MCDA model analysis. Therefore, a comparison has been made with other similar research that had focused on economic and environmental impacts using similar models (Dodgson, et al., 2009; Gentil, et al., 2010; Bilec, et al., 2012). From an academic and professional standpoint, the content of this thesis is beneficial for different construction groups, namely demolition contractors, recyclers, on-site waste producers, aggregate users, and other researchers.

## 6.5 Conclusion

Most existing research in relation to the effective management of C&D waste has focused on assessing the extent of the reduction, recycling, and reuse of C&D waste, rather than the environmental and economic impact of these. Studies relating to environmental and economic analysis of the recycling and reuse of C&D waste are still limited; this study contributes to existing knowledge and appears to be sensitive to data through its detailed analysis of both environmental and economic methods of recycling and reuse. The study has successfully discussed the problem statement and formulated a null hypothesis to justify the overall research outcome.

The preliminary main research question asked 'whether or not LCA and MCDA can be adopted to enhance the economic and environmental benefits of the recycling and reuse of C&D waste'. Based on the research carried out, LCA and AHP (an aspect of MCDA) were applied directly to the two case studies (Medium and Small-scale Demolition and New Build projects) to test and validate the null hypothesis. The null hypothesis was rejected for the two case studies; however, the study supports the idea that LCA and MCDA and believed that these two unique tools can in fact, be used to improve the evaluation of economic and environmental benefits of the recycling and reuse of C&D waste. The development of the decision-support framework enables decision-makers to solicit their input in deciding on policy alternatives appropriate to managing the environmental and economic impact of recycling and reusing C&D waste.

The integration of the two management tools LCA and AHP into a real-life Demolition and New Build project has encouraged the formation of a decision-support framework, which has improved the evaluation of the economic and environmental benefits of the recycling and reuse of C&D waste. This directly provides a valid answer to the main question posed in Chapter 1. Nevertheless, specific questions have been answered through the literature review. To answer Question 1 ('What is the scale of the C&D waste problem and what are the economic and environmental impacts of the C&D waste?') key issues with C&D waste in terms of its economic and environmental impact are carefully discussed in Chapter 2.

The research found that the environmental problems associated with landfills are immense, and that apart from the aesthetic degradation of the area and the destruction of the natural topography and vegetation, landfills can be full of hazardous and toxic substances, which contaminate the ground, the groundwater, and the local area.

To address Question 2 (‘What are the logistic and legislative barriers for reuse of C&D waste?') available literature on waste management legislation was explored and key issues were discussed. Question 3 ('What economic and environmental value can be gained through recycling and reusing of C&D waste') has been answered through the development of the decision-support framework and the application of the new framework to a real-life case study. Question 4 ('What decision-support framework will enable the assessment of effective and efficient reuse of C&D waste?') is the central purpose of the study. This question was answered by the case study validation, which was as a result of the application of the two LCA and MCDA management tools.

To conclude, the newly developed decision-support framework based on the two models (LCA and MCDA) as detailed in Chapter 4 can in fact provide a basis for an improved decision-making support system in relation to the environmental and economic benefits of waste management. Developing such a model will further promote the awareness of sustainability in many local construction sites across the country, if not the entire world. The study is limited in scope to the United Kingdom, as cultures may be different in other countries in relation to C&D waste management. In turn, the key findings herein should become strong incentives for key players, policy makers, and stakeholders to focus more on what materials should be reused or recycled and what should be sent to landfill. The study strongly supports the *‘zero waste initiative’*, however, and rejects the idea of diverting C&D waste to landfill.

# CHAPTER 7: Recommendation for Future Work

## Chapter Aim:

The purpose of the Chapter is to recommend for future works for effective management of C&D waste.

Figure 54: Recommendation for future work

## Chapter Objectives

- **Recommend** future work
- **Suggest** new focus area for extensive research work on C&D waste management

## 7.1 Suggested Future Work

In arriving at a conclusion for this thesis, a few suggestions for future work are discussed. The topics selected here are, in my view, the two key problem areas that have to be addressed in order to contribute to an academic foundation for further development and optimisation of the recycling and reuse of building waste. It is my hope that such work may be carried out in the future with the intention of reducing greenhouse gas emissions and maintaining a cost-effective waste management system.

With the rejection of the null hypothesis, the research carried out and the experience gained through developing and validating the decision-support framework, there is the opportunity to recommend future extensive work that will further analyse the economic and environment impacts using other related management tools. Thus, additional work can be done in the following area:

- The criteria selection process must align with the overall goal and objectives. The selection of criteria as an integral aspect of the study only relates to environmental and economic measures that can be obtained from the waste system decision-making process. There is a need for future work in this area, as criteria types need to address other key areas such as political and social factors for effectively managing C&D waste.

- The decision-support framework developed in this study has considered specific criteria and different policy alternatives. Future work needs to demonstrate the effectiveness of the criteria set in order to measure then against the various policy alternatives.

- There is a need for better understanding of the dynamics in demolition and construction projects in order to analyse the life cycle of specific waste system. Future work is required so the life cycle of waste can be property investigated in terms of LCA inventory analysis.

- The execution of the decision-support framework involving the main case study needs to be extended to other projects. This thesis develops a framework that is able to address two key impacts (i.e. environmental and economic impacts). Future work should be carried out to address other impacts, such as political and social impacts (in terms of employment potential and general acceptance of the recycling and reuse of C&D waste).

- The work performed in this thesis was affected by the limited data collected. By embarking on future work to collect a rich and large set of data and focus on other impacts of the recycling and reuse of C&D waste, future researchers can justify the development of an expanded decision-support system.

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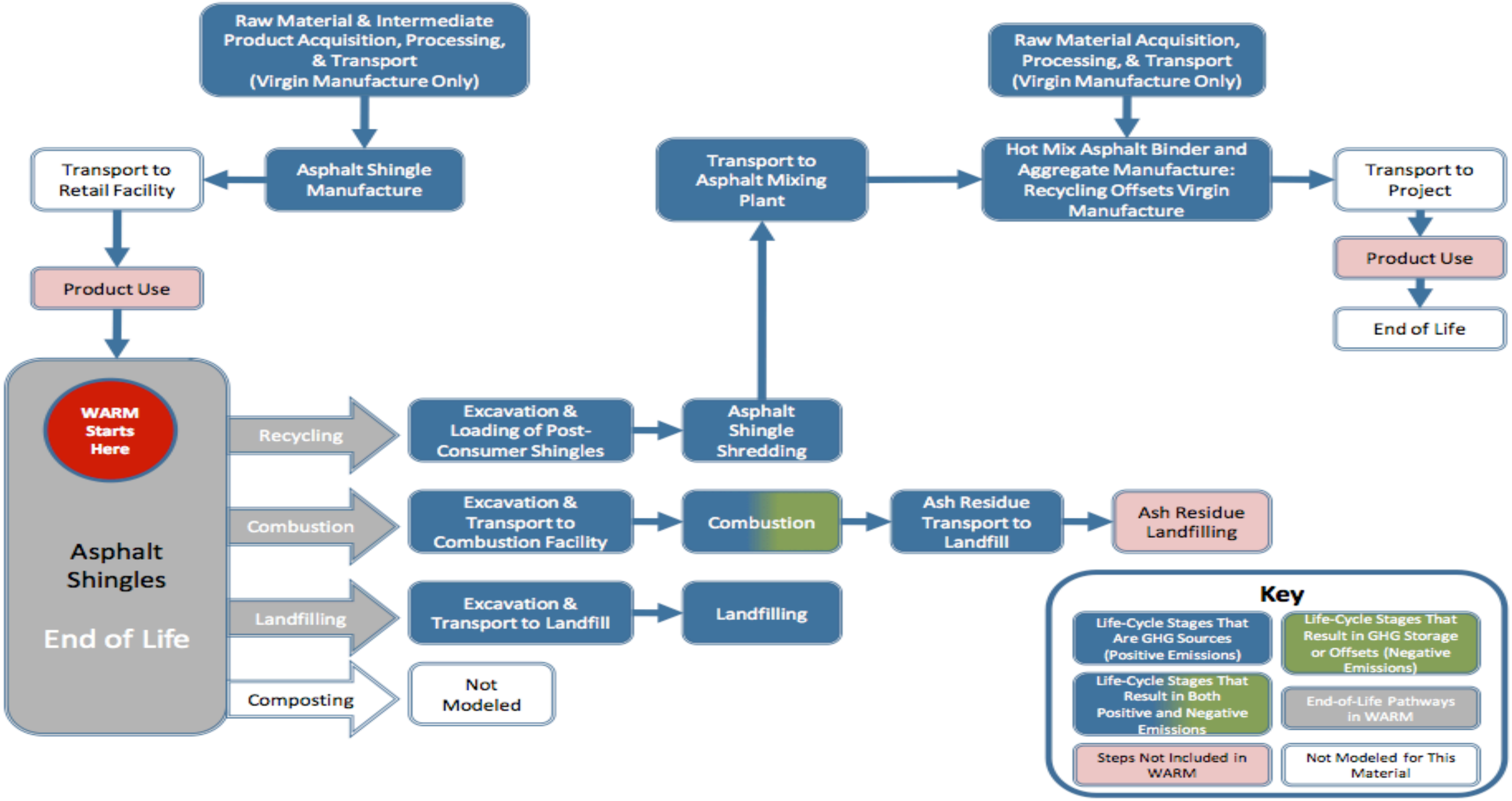
## AVAILABLE STUDY RESOURCES

## Appendix 1 – Demolition Site Layout Plan

## Appendix 2 – Waste Reduction Model

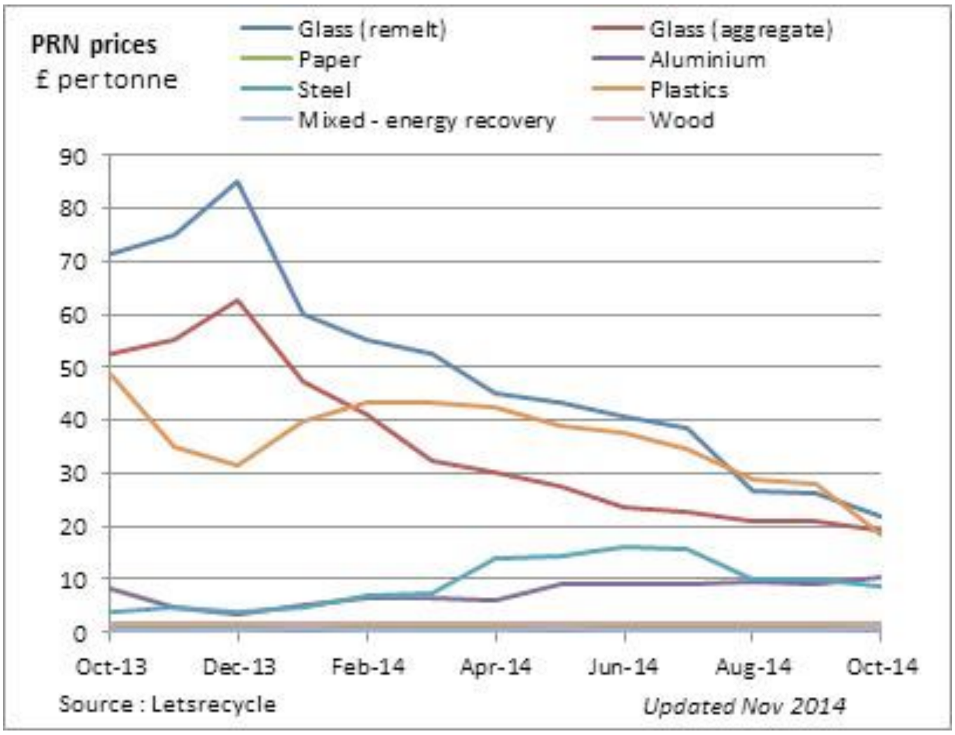


## Appendix 3 – Economic Value of Waste Types

Media Centre Events Jobs Tenders Funding Blog Help

**PRN prices**

A PRN applies for one tonne of material and prices shown are monthly averages. Volume discounts apply, with small purchases attracting higher prices.



Data source: PRN Prices, 2014

| Type | Material | Price Range | Average (£/tonnes) | Comments |
|---|---|---|---|---|
| **Glass** | General mixed | | | Cost estimate taken at Nov 2014 |
| **Paper** | | 10 to 15 | 13 | Cost estimate taken at Nov 2014 |
| **Metal** | | 20 to29 | 24 | Cost estimate taken at Nov 2014 |
| **Mixed -energy recovery** | | 15 to 21 | 18 | Cost estimate taken at Nov 2014 |
| **Aluminium** | | 25 to 30 | 28 | Cost estimate taken at Nov 2014 |
| **Plastics** | | 22 to 28 | 25 | Cost estimate taken at Nov 2014 |
| **Wood** | | 6 to 10 | 8 | Cost estimate taken at Nov 2014 |

Select year 6 2015 Domestic Mill Prices 2014 UK Domestic Mill Prices 2013 UK Domestic Mill prices 2012 UK Domestic Mill prices 2011 UK Domestic Mill prices 2010 UK Domestic Mill prices 2009 UK Domestic Mill Prices 2008 UK Domestic Mill Prices 2007 UK Domestic Mill Prices 2006 UK Domestic Mill prices 2005 UK Domestic Mill prices 2004 UK Domestic Mill prices 2003 UK Domestic Mill prices 2002 UK Domestic Mill prices 2001 UK Domestic Mill prices 2000 UK Domestic Mill prices

Waste paper price indicators for paper recycling in domestic UK mills

2015 £ per tonne ex works January February March April May June

## Appendix 4 – Summary of Projects

**Summary of Projects**

| Project Ref | Type | Value (£m) | Duration (weeks) | Size (m2 floor area) |
|---|---|---|---|---|
| 1 | New build | 109 | 87 | 35210 |
| 2 | New build | 75 | | 23225 |
| 3 | Demolition & new build | 28 | 63 | 12474 |
| 4 | Refurbishment | 30 | 12 | 17938 |
| 5 | Refurbishment | 20 | | |
| 6 | New build | 88 | | 32516 |
| 7 | Refurbishment | 172 | | 50000 |
| 8 | Refurbishment | 12.5 | 53 | 9290 |
| 9 | | | | |
| 10 | Refurbishment | 700 | 260 | 495184 |
| 11 | New build | 50 | 94 | 22000 |
| 12 | New build | 8 | 100 | 2100 |
| 13 | New build | 85 | 104 | 330000 |
| 14 | | | | |
| 15 | Demolition & new build | 12 | 100 | 2000 |
| 16 | New build | 95 | 100 | 42000 |
| 17 | | | | |
| 18 | Demolition & new build | 50 | | |
| 19 | | | | |
| 20 | New build | 68 | | 21000 |
| 21 | Refurbishment | 2.5 | 56 | 1500 |
| 22 | New build | 201 | | |
| 23 | New build | 35 | | |
| 24 | Refurbishment | 30 | | |
| 25 | New build | 30 | | 11500 |
| 26 | New build | 170 | 64 | 57971 |
| 27 | Refurbishment | 37 | 40 | 31000 |
| 28 | Demolition & new build | 27 | 132 | 10500 |
| 29 | New build | 54 | 92 | 20400 |
| 30 | Demolition & new build | 14 | | |
| 31 | New build | 97 | 100 | 37601 |
| 32 | New build | 33.4 | 87 | 14378 |
| 33 | New build | 150 | | 52025 |
| 34 | New build | 61 | | 148000 |
| 35 | Demolition & new build | 150 | | 58528 |
| 36 | | | | |
| 37 | New build | 26 | 1 | 11360 |
| 38 | New build | 1.7 | 35 | 546 |

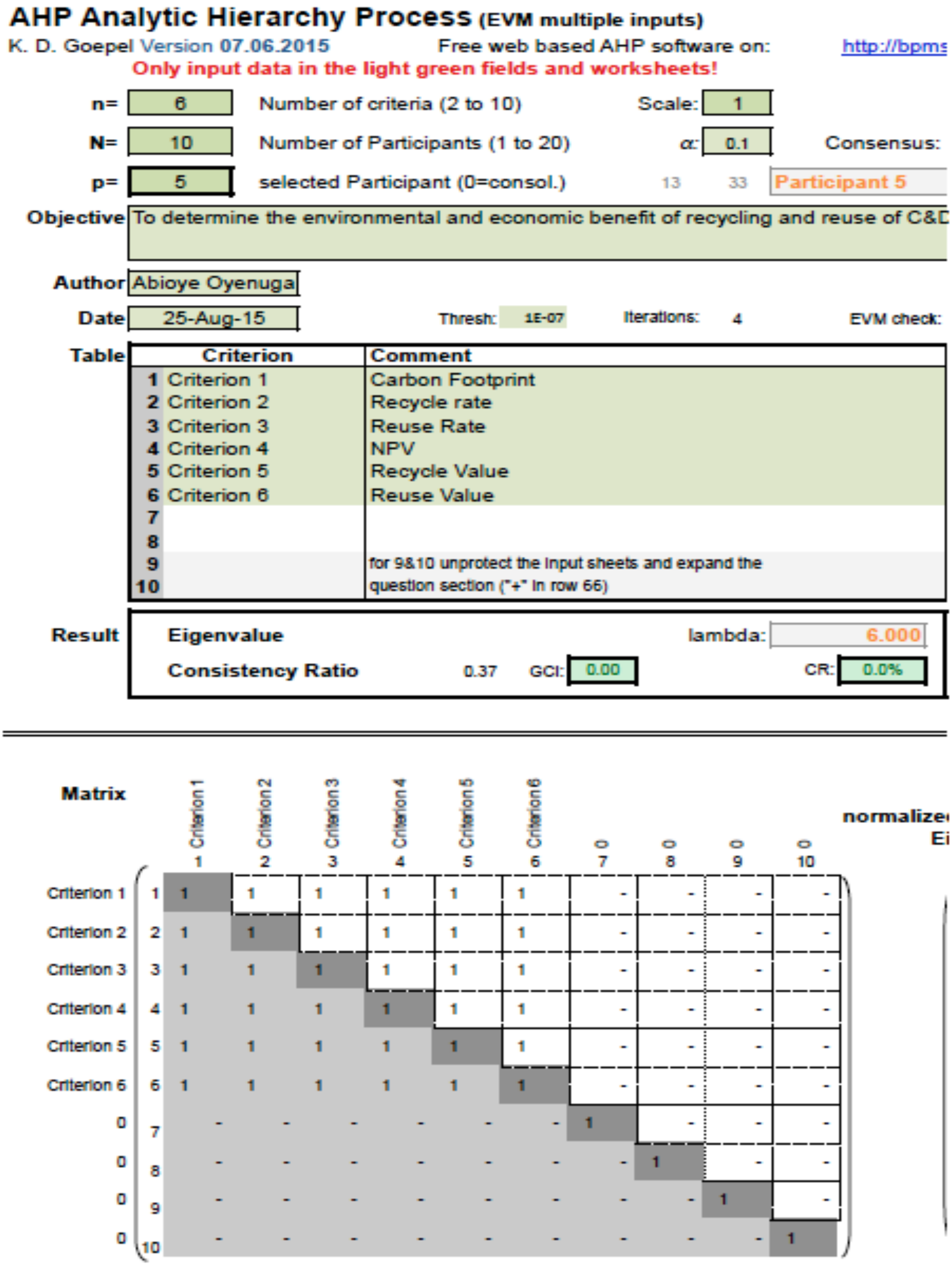
## Appendix 5 – Schedule of National Recycling Capped Rates

**Schedule of National Capped Rates**

| | Container type | Container size | Dry Mixed Recycling Rates | General Mixed Rates | Inc Tonnage | Excess Tonnage Rates | Inert Waste Rates |
|---|---|---|---|---|---|---|---|
| | Wheelie Bin | 1100 Litre | £7.40 | £12.16 | | £- | £- |
| | Wheelie Bin | 660 Litre | £6.87 | £10.05 | | £- | £- |
| London North | Wheelie Bin | 240 Litre | £5.82 | £6.87 | | £- | £- |
| | Skip | 4 cubic yard | £- | £169.20 | | £- | £158.63 |
| | Skip | 6 cubic yard | £- | £211.50 | | £- | £200.93 |
| | Skip | 8 cubic yard | £- | £222.08 | | £- | £206.21 |
| | Skip | 12 cubic yard | £- | £280.24 | | £- | £- |
| | Roll on Roll Off | 20 cubic yard | £- | £417.71 | 3 | £100.46 | £370.13 |
| | Roll on Roll Off | 40 cubic yard | £- | £417.71 | 3 | £100.46 | £- |
| London South | Wheelie Bin | 1100 Litre | £7.40 | £12.16 | | £- | £- |
| | Wheelie Bin | 660 Litre | £6.87 | £10.05 | | £- | £- |
| | Wheelie Bin | 240 Litre | £5.29 | £6.35 | | £- | £- |
| | Skip | 4 cubic yard | £- | £153.34 | | £- | £142.76 |
| | Skip | 6 cubic yard | £- | £200.93 | | £- | £190.35 |
| | Skip | 8 cubic yard | £- | £216.79 | | £- | £190.35 |
| | Skip | 12 cubic yard | £- | £264.38 | | £- | £- |
| | Roll on Roll Off | 20 cubic yard | £- | £417.71 | 3 | £100.46 | £- |
| | Roll on Roll Off | 40 cubic yard | £- | £417.71 | 3 | £100.46 | £- |

# Appendix 6 – Sample of AHP software to determine Consistency Ratio

## Case study 1 – AHP estimate



**AHP Analytic Hierarchy Process (EVM multiple inputs)**

K. D. Goepel Version 07.06.2015 Free web based AHP software on: http://bpms

Only input data in the light green fields and worksheets!

n= 6 Number of criteria (2 to 10) Scale: 1

N= 10 Number of Participants (1 to 20) α: 0.1 Consensus:

p= 5 selected Participant (0=consol.) 13 33 Participant 5

Objective: To determine the environmental and economic benefit of recycling and reuse of C&D

Author: Abioye Oyenuga

Date: 25-Aug-15 Thresh: 1E-07 Iterations: 4 EVM check:

Table

| | Criterion | Comment |
|---|---|---|
| 1 | Criterion 1 | Carbon Footprint |
| 2 | Criterion 2 | Recycle rate |
| 3 | Criterion 3 | Reuse Rate |
| 4 | Criterion 4 | NPV |
| 5 | Criterion 5 | Recycle Value |
| 6 | Criterion 6 | Reuse Value |
| 7 | | |
| 8 | | |
| 9 | | for 9&10 unprotect the input sheets and expand the |
| 10 | | question section ("+" in row 66) |

Result

Eigenvalue lambda: 6.000

Consistency Ratio 0.37 GCI: 0.00 CR: 0.0%

Matrix

| | | Criterion 1<br>1 | Criterion 2<br>2 | Criterion 3<br>3 | Criterion 4<br>4 | Criterion 5<br>5 | Criterion 6<br>6 | 0<br>7 | 0<br>8 | 0<br>9 | 0<br>10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Criterion 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| Criterion 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| Criterion 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| Criterion 4 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| Criterion 5 | 5 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| Criterion 6 | 6 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| 0 | 7 | - | - | - | - | - | - | 1 | - | - | - |
| 0 | 8 | - | - | - | - | - | - | - | 1 | - | - |
| 0 | 9 | - | - | - | - | - | - | - | - | 1 | - |
| 0 | 10 | - | - | - | - | - | - | - | - | - | 1 |

normalize
Ei

sg.com

Linear

100.0%

) waste

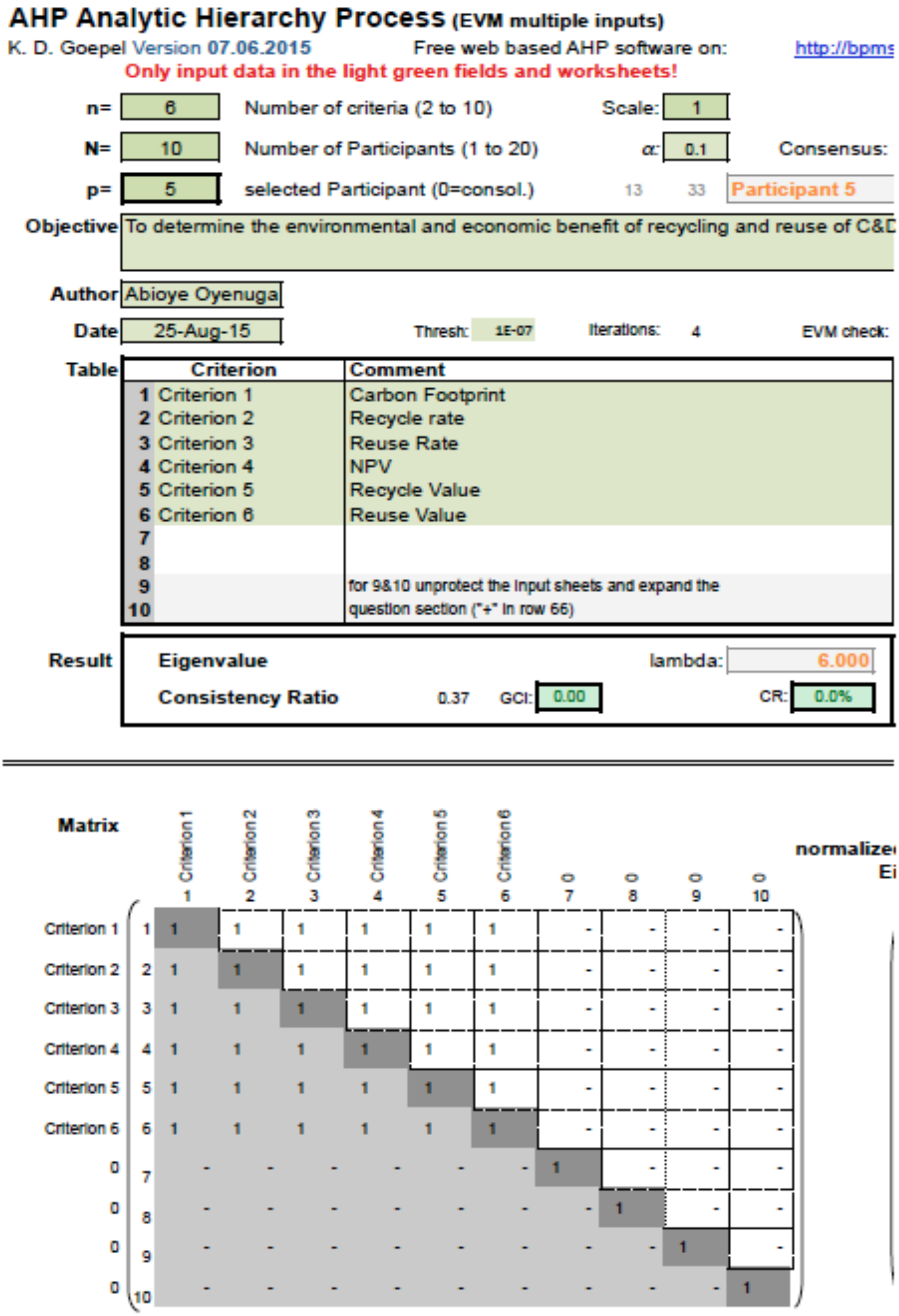
7.6E-08

| Weights | Rk |
|---|---|
| 74.0% | 1 |
| 17.0% | 4 |
| 9.0% | 6 |
| 62.0% | 2 |
| 26.0% | 3 |
| 12.0% | 5 |
| 0.0% | |
| 0.0% | |
| 0.0% | |
| 0.0% | |

**d principal igenvector**

$$\begin{pmatrix} 16.67\% \\ 16.67\% \\ 16.67\% \\ 16.67\% \\ 16.67\% \\ 16.67\% \\ 0.00\% \\ 0.00\% \\ 0.00\% \\ 0.00\% \end{pmatrix}$$

## Case study 2 – AHP estimate



**AHP Analytic Hierarchy Process (EVM multiple inputs)**

K. D. Goepel Version 07.06.2015 Free web based AHP software on: http://bpms

**Only input data in the light green fields and worksheets!**

**n=** 6 Number of criteria (2 to 10) Scale: 1

**N=** 10 Number of Participants (1 to 20) α: 0.1 Consensus:

**p=** 5 selected Participant (0=consol.) 13 33 Participant 5

**Objective** To determine the environmental and economic benefit of recycling and reuse of C&D

**Author** Abioye Oyenuga

**Date** 25-Aug-15 Thresh: 1E-07 Iterations: 4 EVM check:

**Table**

| | Criterion | Comment |
|---|---|---|
| 1 | Criterion 1 | Carbon Footprint |
| 2 | Criterion 2 | Recycle rate |
| 3 | Criterion 3 | Reuse Rate |
| 4 | Criterion 4 | NPV |
| 5 | Criterion 5 | Recycle Value |
| 6 | Criterion 6 | Reuse Value |
| 7 | | |
| 8 | | |
| 9 | | for 9&10 unprotect the input sheets and expand the |
| 10 | | question section ("+" in row 66) |

**Result**

**Eigenvalue** lambda: 6.000

**Consistency Ratio** 0.37 GCI: 0.00 CR: 0.0%

**Matrix**

| | | Criterion 1<br>1 | Criterion 2<br>2 | Criterion 3<br>3 | Criterion 4<br>4 | Criterion 5<br>5 | Criterion 6<br>6 | 0<br>7 | 0<br>8 | 0<br>9 | 0<br>10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Criterion 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| Criterion 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| Criterion 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| Criterion 4 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| Criterion 5 | 5 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| Criterion 6 | 6 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| 0 | 7 | - | - | - | - | - | - | 1 | - | - | - |
| 0 | 8 | - | - | - | - | - | - | - | 1 | - | - |
| 0 | 9 | - | - | - | - | - | - | - | - | 1 | - |
| 0 | 10 | - | - | - | - | - | - | - | - | - | 1 |

**normalize**
**Ei**

sg.com

Linear

100.0%

waste

7.6E-08

| Weights | Rk |
|---|---|
| 63.0% | 2 |
| 25.0% | 3 |
| 12.0% | 5 |
| 72.0% | 1 |
| 18.0% | 4 |
| 10.0% | 6 |
| 0.0% | |
| 0.0% | |
| 0.0% | |
| 0.0% | |

**d principal**
**igenvector**

$$\begin{pmatrix} 16.67\% \\ 16.67\% \\ 16.67\% \\ 16.67\% \\ 16.67\% \\ 16.67\% \\ 0.00\% \\ 0.00\% \\ 0.00\% \\ 0.00\% \end{pmatrix}$$

## Pairwise comparisons estimate (Matrix formation)

Carbon Footprint (CF), Recycle Rate (RR), Reuse Rate (ReR), NPV, Recycle Value (RV), Reuse Value (ReV)

**Carbon Footprint**

- CF – RR 1/9 (CF is 9 times more important than RR)
- CF – ReR 1/5 (CF is 5 times more important than ReR)
- CF – NPV 1 (CF is equal important to NPV)
- CF – RV 1/3 (CF is 3 times more important than RV
- CF – ReV ½ (CF is 3 times more important than ReV)

**Recycle Rate**

- RR – RR 1 Equal importance
- RR – ReR 1 Equal importance
- RR – NPV 1/3 (RR is 3 times more important than NPV)
- RR – RV ½ (RR is 2 times more important than RV)
- RR – ReV 1 (RR is of equal importance to ReV)

**Reuse Rate**

- ReR – ReR 1 Equal importance
- ReR – RR 1 Equal importance
- ReR – NPV 5 (NPV has strong importance as compared with ReR)
- ReR – RV 3 (RV is 3 times important than ReR)
- ReR – ReV ½ (ReR is 2 times important than ReV)

**NPV**

- NPV – RR 3 (NPV is 3 times important than RR)
- NPV – ReR 5 (NPV is 5 times important than ReR)
- NPV – NPV 1 equal importance
- NPV – RV 9 (NPV is 9 times more important than RV)
- NPV – ReV (NPV is 9 times more important then ReV

## Appendix 7 - Questionnaire Sample

### Waste Policy Acceptability

1. What is your Occupation?

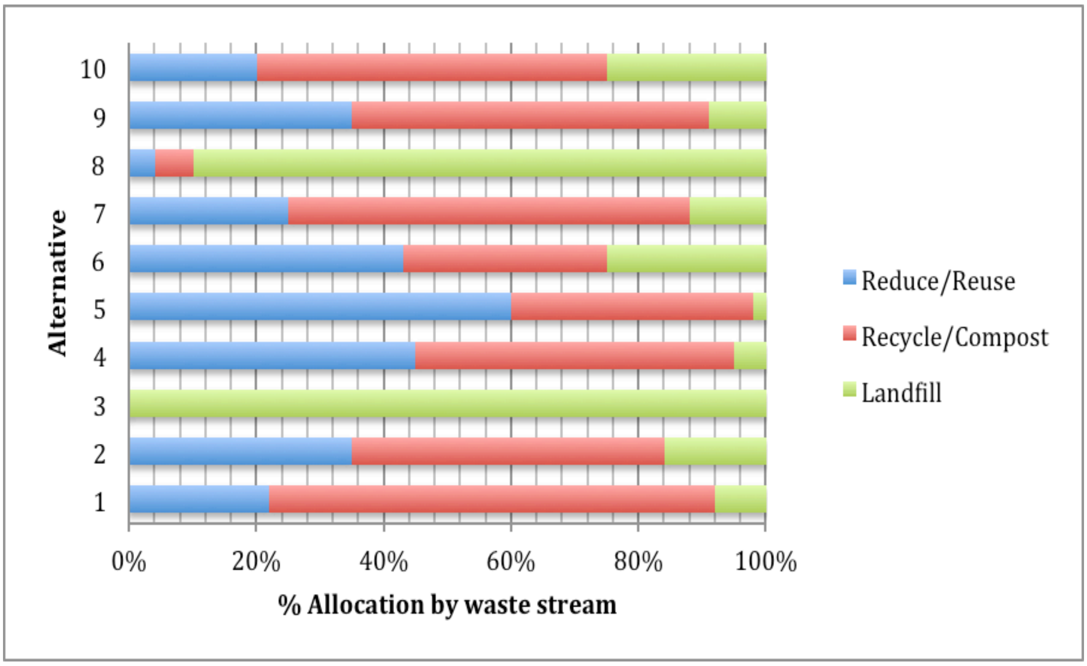
A. Project Manager

**B.** Site Manager

**C.** Architect

**D.** Quantity Surveyor

**E.** Other, Please specify ----------------------------------------------------



The above chart represents different waste management alternatives for a typical Demolition and New Build project. Alternative 1, means that 8% of all the waste, which the demolition construction site produces, is being diverted to landfill, 22% reduced or reused, 70% of waste being recycled. It then progress to option 5, as shown above a 60% less waste has been produced, 38% all further waste is recycled and only 2% of waste is then diverted to landfill, Option 10 shows that 20% of waste has been reduced/reused, 55% of all waste is then recycled and only 25% of waste sent to landfill.

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

Recycle – is that waste which is created, is diverted to recycled facilities. The waste does therefore not end up on a landfill.

Landfill – means that all waste that is generated will go of the North London landfill.

2. For the alternative below rank the acceptability of each one (1 – completely unacceptable, 5 – acceptable and 10 – strongly acceptable)

| | | | | ← | | | → | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Alternative 1 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Alternative 2 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Alternative 3 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Alternative 4 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Alternative 5 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Alternative 6 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Alternative 7 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Alternative 8 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Alternative 9 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Alternative 10 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

4. Please match the type of opportunity for the following waste inventory data stages

**Stages**
**Opportunities**

A. Transportation Job Creation

B. Processing Energy
Use

C. Disposal CO2 reduction

D. Reuse/Recycle New Product Development

5. Which of the following provides better employment potential in a waste system?

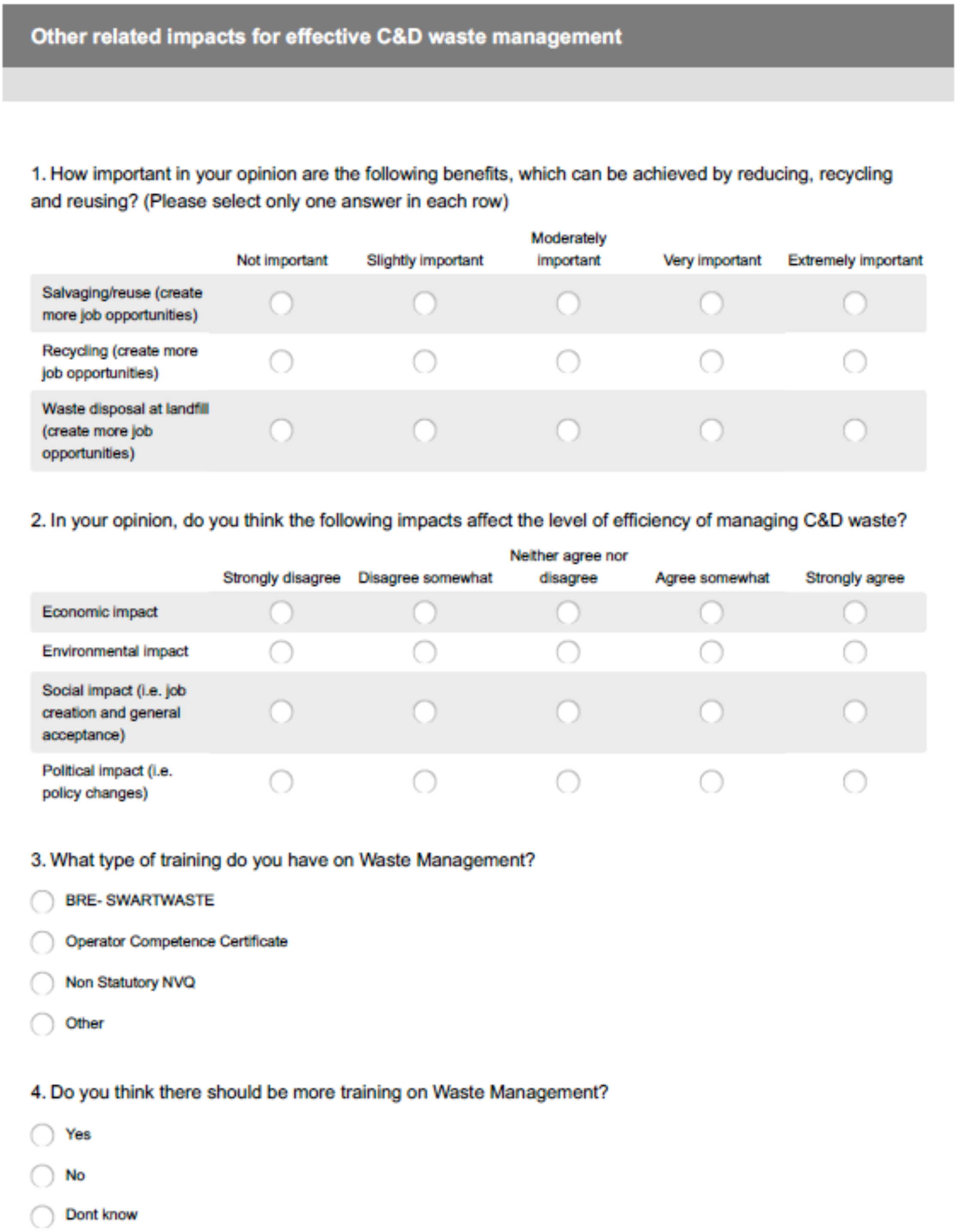
   A. Disposal

   B. Recycling

   C. Salvaging/Reuse

   D. Others.

## Questionnaire on Impact Category



**Other related impacts for effective C&D waste management**

1. How important in your opinion are the following benefits, which can be achieved by reducing, recycling and reusing? (Please select only one answer in each row)

| | Not important | Slightly important | Moderately important | Very important | Extremely important |
|---|---|---|---|---|---|
| Salvaging/reuse (create more job opportunities) | ○ | ○ | ○ | ○ | ○ |
| Recycling (create more job opportunities) | ○ | ○ | ○ | ○ | ○ |
| Waste disposal at landfill (create more job opportunities) | ○ | ○ | ○ | ○ | ○ |

2. In your opinion, do you think the following impacts affect the level of efficiency of managing C&D waste?

| | Strongly disagree | Disagree somewhat | Neither agree nor disagree | Agree somewhat | Strongly agree |
|---|---|---|---|---|---|
| Economic impact | ○ | ○ | ○ | ○ | ○ |
| Environmental impact | ○ | ○ | ○ | ○ | ○ |
| Social impact (i.e. job creation and general acceptance) | ○ | ○ | ○ | ○ | ○ |
| Political impact (i.e. policy changes) | ○ | ○ | ○ | ○ | ○ |

3. What type of training do you have on Waste Management?

○ BRE- SWARTWASTE

○ Operator Competence Certificate

○ Non Statutory NVQ

○ Other

4. Do you think there should be more training on Waste Management?

○ Yes

○ No

○ Dont know

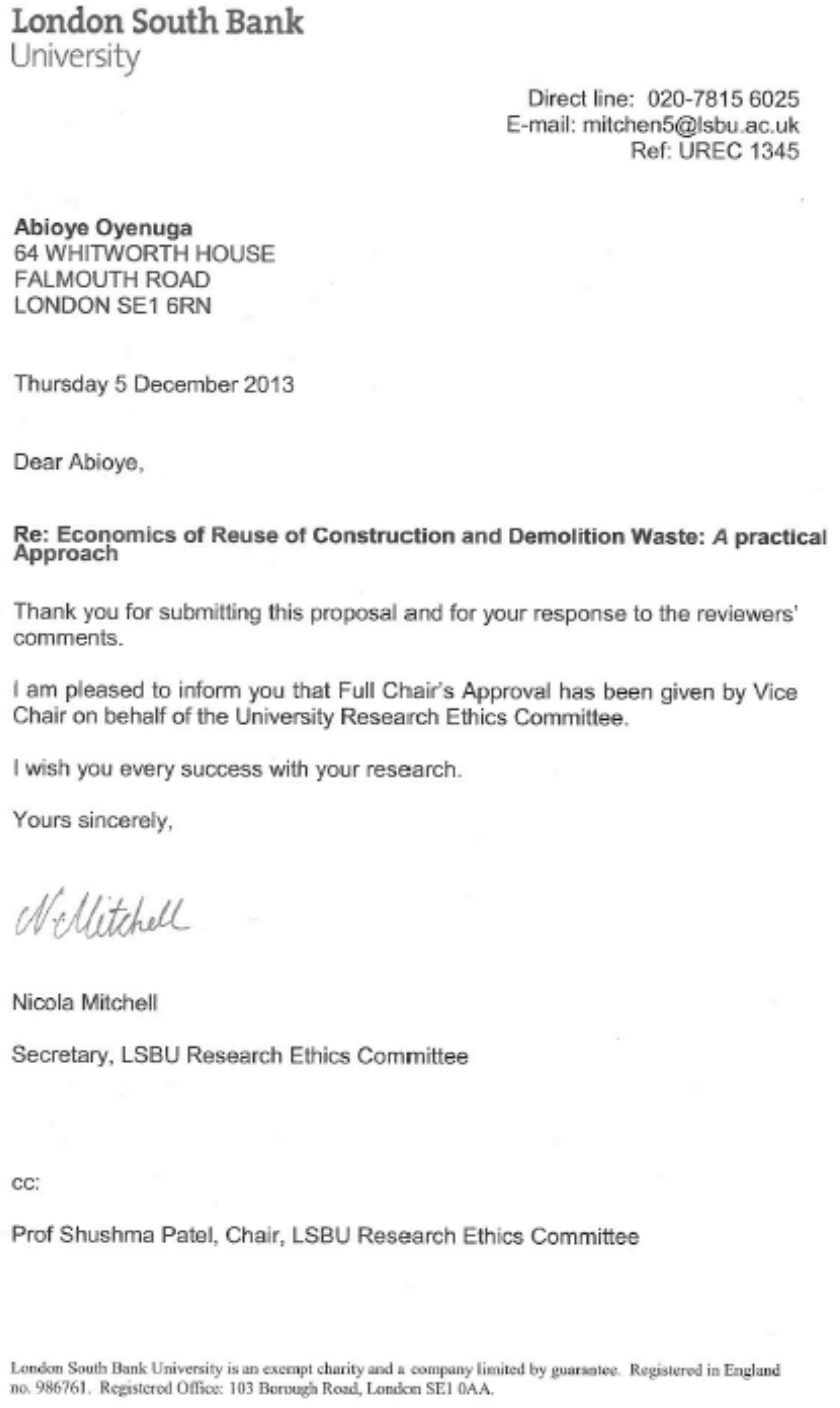
4. Do you think there should be more training on Waste Management?

○ Yes

○ No

○ Dont know

## Appendix 8: University Ethics Committee Approval



London South Bank
University

Direct line: 020-7815 6025
E-mail: mitchen5@lsbu.ac.uk
Ref: UREC 1345

**Abioye Oyenuga**
64 WHITWORTH HOUSE
FALMOUTH ROAD
LONDON SE1 6RN

Thursday 5 December 2013

Dear Abioye,

**Re: Economics of Reuse of Construction and Demolition Waste: *A* practical Approach**

Thank you for submitting this proposal and for your response to the reviewers' comments.

I am pleased to inform you that Full Chair's Approval has been given by Vice Chair on behalf of the University Research Ethics Committee.

I wish you every success with your research.

Yours sincerely,

N Mitchell

Nicola Mitchell

Secretary, LSBU Research Ethics Committee

cc:

Prof Shushma Patel, Chair, LSBU Research Ethics Committee

## Appendix 9 – Waste Disposal and Recycle Fees

London
Solid Waste Management
2015-02-12
Solid Waste Management | Thursday, February 12, 2015

### W12A Landfill Fees

The W12A Landfill Site accepts cash; debit, credit and payment on account (please note account application process requires two weeks for set up). See below for fees and charges at the Community EnviroDepots. Please note that the EnviroDepots accept debit or credit payment only for construction, renovation & roofing materials.

### W12A Landfill Disposal Fees - Residential Waste

| | |
|---|---|
| • 0 - 100 kg | $8.00 |
| • 101 - 200 kg | $15.00 |
| • 201 - 400 kg | $30.00 |
| • 401 - 600 kg | $45.00 |
| • 601 - 800 kg | $60.00 |
| • 801 - 1,000 kg | $75.00 |
| > 1,000 kg | $75.00 per tonne |

NOTE: Construction and demolition waste are banned from the Landfill.

### W12A Landfill Disposal Fees - Standard Fees

Business Waste $75.00 per tonne
Waste from Outside Service Area Accepted Under Ministerial Order $150.00 per tonne
Minimum Charge - excluding residential/ charitable organization waste $75.00 per transaction

**W12A Landfill Disposal Fees - Pre-approved Fees**

Charitable Organization Waste $0.00 per tonne

Daily Cover Waste $9.00 per tonne

Brownfield Waste $31.00 per tonne

Recycling Process Residuals $40.00 per tonne

Recycling Process Residuals - reduced fee 1- charge account only; minimum monthly fee $9,750.00: $37.00 per tonne

Business Waste - reduced fee 1- charge account only; minimum monthly fee $12,750.00: $47.00 per tonne effective January 1, 2013

Business Waste - reduced fee 2 - charge account only; minimum monthly fee $38,500.00: $43.00 per tonne effective January 1, 2013

Asbestos Waste $350 for first load, $100 per subsequent load plus $75 per tonne

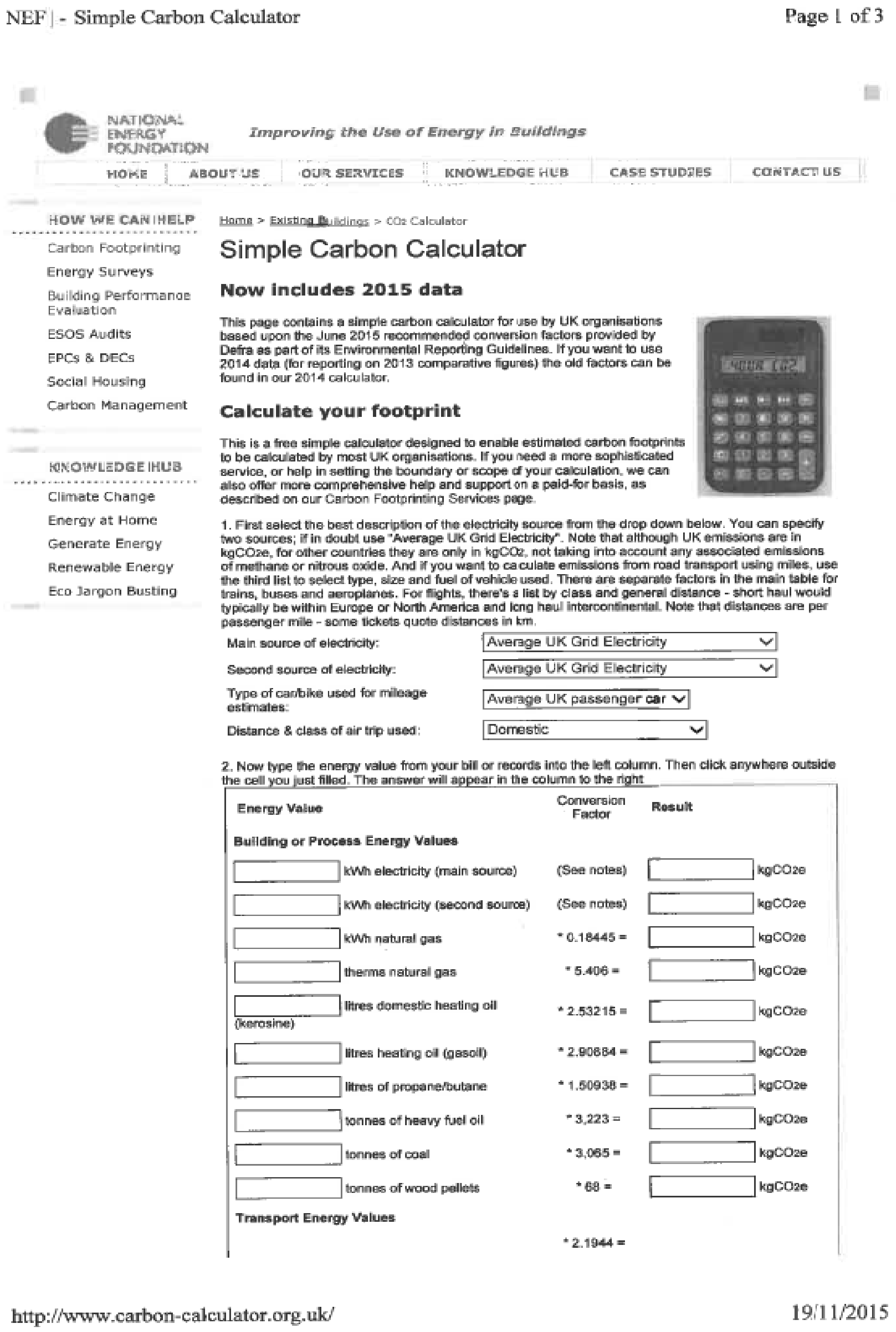
**Try Recycling Fees (21463 Clarke Road)**

- Grass clippings: $1.50 per bag
- Leaves: No charge

**Waste Collection Fees**

- Multi-residential properties - second collection per week: $4.50 per unit, per year
- Multi-residential properties - extra collections: $130.00 per hour
- Multi-residential buildings - bin rental $25.00 per month per bin
- Waste Management By-law WM12 Part 12 (Owner has failed to comply with WM12,
- Part 12; City collects waste at expense of owner): $130.00 per hour; $130.00 minimum per event

## Appendix 10 – Carbon Footprint Measurement



NEF | - Simple Carbon Calculator Page 1 of 3

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- Generate Energy
- Renewable Energy
- Eco Jargon Busting

Home > Existing Buildings > CO₂ Calculator

# Simple Carbon Calculator

## Now includes 2015 data

This page contains a simple carbon calculator for use by UK organisations based upon the June 2015 recommended conversion factors provided by Defra as part of its Environmental Reporting Guidelines. If you want to use 2014 data (for reporting on 2013 comparative figures) the old factors can be found in our 2014 calculator.

## Calculate your footprint

This is a free simple calculator designed to enable estimated carbon footprints to be calculated by most UK organisations. If you need a more sophisticated service, or help in setting the boundary or scope of your calculation, we can also offer more comprehensive help and support on a paid-for basis, as described on our Carbon Footprinting Services page.

1. First select the best description of the electricity source from the drop down below. You can specify two sources; if in doubt use "Average UK Grid Electricity". Note that although UK emissions are in kgCO2e, for other countries they are only in kgCO2, not taking into account any associated emissions of methane or nitrous oxide. And if you want to calculate emissions from road transport using miles, use the third list to select type, size and fuel of vehicle used. There are separate factors in the main table for trains, buses and aeroplanes. For flights, there's a list by class and general distance - short haul would typically be within Europe or North America and long haul intercontinental. Note that distances are per passenger mile - some tickets quote distances in km.

| | |
|---|---|
| Main source of electricity: | Average UK Grid Electricity |
| Second source of electricity: | Average UK Grid Electricity |
| Type of car/bike used for mileage estimates: | Average UK passenger car |
| Distance & class of air trip used: | Domestic |

2. Now type the energy value from your bill or records into the left column. Then click anywhere outside the cell you just filled. The answer will appear in the column to the right

| Energy Value | | Conversion Factor | Result | |
|---|---|---|---|---|
| **Building or Process Energy Values** | | | | |
| | kWh electricity (main source) | (See notes) | | kgCO2e |
| | kWh electricity (second source) | (See notes) | | kgCO2e |
| | kWh natural gas | * 0.18445 = | | kgCO2e |
| | therms natural gas | * 5.406 = | | kgCO2e |
| | litres domestic heating oil (kerosine) | * 2.53215 = | | kgCO2e |
| | litres heating oil (gasoil) | * 2.90884 = | | kgCO2e |
| | litres of propane/butane | * 1.50938 = | | kgCO2e |
| | tonnes of heavy fuel oil | * 3,223 = | | kgCO2e |
| | tonnes of coal | * 3,065 = | | kgCO2e |
| | tonnes of wood pellets | * 68 = | | kgCO2e |
| **Transport Energy Values** | | | | |
| | | * 2.1944 = | | |

http://www.carbon-calculator.org.uk/ 19/11/2015

## Appendix 11

## Academic Paper 1

Oyenuga, A. A. and Bhamidimarri, R. (2015), "Reduce, Reuse and Recycle: Grand Challenges in Construction Recovery Process", Paper submitted *International Journal of Social, Behaviour, Educational, Economic and Management Engineering*

# Reduce, Reuse and Recycle: Grand Challenges in Construction Recovery Process

Abioye A. Oyenuga, Rao Bhamidimarri

International Science Index Vol:9, No:4, 2015 waset.org/Publication/10000965

***Abstract*****—**Hurling a successful Construction and Demolition Waste (C&DW) recycling operation around the globe is a challenge today, predominantly because secondary materials markets are yet to be integrated. Reducing, Reusing and recycling of (C&DW) have been employed over the years, and various techniques have been investigated. However, the economic and environmental viability of its application seems limited. This paper discusses the costs and benefits in using secondary materials and focus on investigating reuse and recycling process for five major types of construction materials: concrete, metal, wood, cardboard/paper and plasterboard. Data obtained from demolition specialists and contractors are considered and evaluated. The research paper found that construction material recovery process fully incorporate a 3R's principle contributing to saving energy and natural resources. This scrutiny leads to the empathy of grand challenges in construction material recovery process. Recommendations to deepen material recovery process are also discussed.

***Keywords*****—**Construction & Demolition Waste (C&DW), 3R concept, Recycling, Reuse, Life-Cycle Assessment (LCA), Waste Management.

## I. INTRODUCTION

IN a broad sense, recycling is part of an ethic of resource efficiency – of using products to their fullest potential. When a recycled material, rather than a raw material, is used to make a new product, natural resources and energy are conserved. This is because recycled materials have already been refined and processed once; manufacturing the second time is much cleaner and less energy-intensive than the first [1]. Waste generated in construction works seemed to have caused serious environmental problems in many cities around the world for so many years [2]. In the United Kingdom, construction and demolition sectors generate more waste and are known as the largest producers of hazardous waste. These sectors are responsible for producing over 36 million tonnes of landfill waste every year. This is approximately 35% of total waste generated, with domestic residential waste accounting for an additional 10%. The construction and demolition sectors are under increasing pressure to improve performance, reduce, reuse and increase recycling opportunities [3]. Public opinion in the UK has emphasised the difficulties of minimising construction waste, but with Germany recycling over 80% of its construction waste and Denmark over 90%, this is clearly a misperception. The UK has recently improved the recovery capacity in recent times [4]. Construction, demolition, and refurbishment works account for around 100 million tonnes of waste in the UK every year [6]. In the US, about 250 million tonnes of municipal solid waste (MSW) was generated each year [5]. At the current per capita rate, an average US weighing 180 pounds generates their own weight in MSW every 41 days. In comparison, the generation rates are 2.8 in Sweden, 3.5 in Germany, and 3.2 in the UK [7]. Interestingly, the US reuse and recycling practices as well as the regulations differ by locality, but still major cities can boost of having significant effort to reduce the amount of C&D waste going to landfill.

Reducing waste is a priority for the European Union and the UK Government and there are many new regulations, measures and targets to reduce waste within the construction. Despite the significant effort seen in reuse and recycling opportunities local construction and demolition contractors are still facing greater challenges in reducing waste to a minimum around the globe. The practice involve reduce, reuse, recycle (3Rs) as well as regulation for C&DW have been influenced by the EU legislation related to waste national recycling goals and incentives. In 2007, a waste strategy was introduced in England [3]. This strategy drives the initiative to reduce the amount of C&D waste being diverted to landfill through reuse and recycling incentives. Following these incentives, there is a duty to ensure that construction materials and activities within adhere with environmental demands through waste minimisation process.

One of the great challenges to waste minimisation on a number of construction sites is the inability to devise an appropriate method of reducing and/or preventing waste In order to close this gap, a unique waste minimisation tool known Site Methodology to Audit Reduced Target Waste (SMART Waste) was proposed by McGrath in 2001. This tool is designed as a benchmark in order to audit, reduce, and target construction waste to enhance greater material recovery for reuse and recycling waste [8]. Despite the significant effort seen in producing secondary materials (i.e. recyclable materials such as concrete, metal, wood, paper, plastics etc.) there are key challenges local contractors are facing in terms of lack of incentives and economic incitement [1]. Yet, there are limited studies within the field of construction waste management indicating why specific measures are set and how effective these really are in practice.

This paper reviews existing literature within waste management practices and discuss the costs and benefits in using secondary materials as well as it focused on

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R. Bhamidimarri is with the School of the Built Environment and Architecture, London Southbank University 103 Borough Road, London, UK (phone: 0207-815-8080; e-mail: bhamidir@lsbu.ac.uk)

investigating reuse and recycling process for five major types of construction materials: concrete, metal, wood, cardboard/paper and plasterboard. Data obtained from demolition specialist and contractors are considered and evaluated. The key challenges in construction material recovery process by incorporating the 3R's principle (reduce, reuse and recycle) are discussed. Consequently, the research findings can lead to developing techniques to enhance better reuse and recycling operations and promotes better economic viability for specific construction waste materials.

### *A. 3R's Principle – Managing Construction Waste*

Managing C&D waste has become one of the major environmental problems in the world. Tremendous amounts of waste have been generated from ongoing new construction works, as well as refurbishment and demolition works. Waste management covers the collection, transporting, storage, treatment, recovery and disposal of waste [9]-[11]. On-site sorting of construction and demolition is one of the most effective and reliable techniques to manage C&D waste [12]. C&DW is made up of both inert (soil, bricks, concrete etc.) and non-inert waste such as plastics, glass, wood, paper etc. [13]. The separation techniques often attract advance technology options and legislative control.

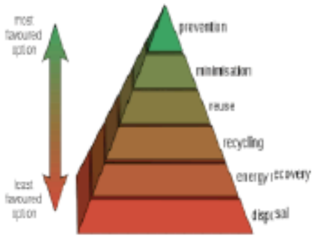

Fig. 1 Waste Management Hierarchy [19]

Waste management concept is guided by level of hierarchy known as the 3R's principle explained by El-Haggar in 2007[19]. This model produces an integrated approach in which options of waste management can be considered and thus serves as a systematic tool for those who generate and manage waste [10]. El-Haggar argued that when waste is being managed effectively it could generate various benefits through the whole life cycle of the waste from its generation to its end disposal [10]. Significantly, it is believed that proper construction waste management will provide both economic and environmental benefits. A number of construction firms as well as the environment at large will benefit through the cost reduction process involved in waste management.

The economic and environment benefits expected from waste minimization are relatively essential as it drives towards the opportunity seen in recycling and the possibilities of selling secondary waste materials as well as the meeting targets on reducing the number of C&D waste being diverted to landfill [14]. Although the transfer of waste to landfill often attracts associated fees/charges and this can be minimized if only waste stream from construction are effectively managed. Interestingly, the process of waste minimization can enhance high competition among local contractors through reducing production cost and create better company profile. Sadly, only a few local contractors had focused on the impact of waste on the environment and have created the idea of recycling construction and demolition waste in a number of municipals [15]. Apart from the two benefits (i.e. economic and the environment), waste minimization can also contribute positively to the following: reduction of landfill spaces, enhance resource management and improve productivity and quality management [13].

#### 1. Life Cycle Assessment (LCA)

Environmental impacts is considered for all waste products and from a resource standpoint the waste hierarchy often led to the most resource-efficient and environmentally sound choice and positive outcomes. LCA support decision-making in the field of waste management and also support determine environmental viability. This approach can help policy makers understand the benefits and trade-offs they have encounter when making decisions on waster management strategies. Significantly, LCA provides a scientifically sound approach to ensure that the best outcome for the environment can be identified and implemented [16]. The LCA is a popular tool used in a number of tools [15]. The tool is often used to investigate the potential environmental impacts, throughout a product's life. A number of research studies believed that waste is produced in different types and quantities throughout the lifecycle of a building with the bulk of the waste produced by from building operations such as construction and demolition phases and not necessarily that generated by building occupants [17]. The lifecycle of a building can be determined by the use of materials and the waste generated throughout the building lifecycle. The most innovative approach to this is the challenge to reduce, recover, reuse and recycle these waste that follow the variety of waste streams leading to landfill.

### *B. Key Challenges*

Managing construction and demolition waste on-site is a complex and challenging activity. Many barriers and opportunities exist in developing a strategy of waste reduction on construction sites. The major problem with managing waste in construction is the increase in management and recycling operation cost, lack of government legislation control, environmental impact, lack of trained staffs and expertise, lack of reuse and recycling incentives [18]. The rise in recycling operation cost may be the major concern for local contractors and other recycling consultants. With the view of these problems outlined above, there is a need to understand and consider various options that could be utilized; a hierarchy of disposal options needs to be considered from low to high impacts. Important waste management strategies known as the '3Rs' (reusing, recycling and reducing) is a way forward in achieving a better outcome in managing construction waste stream as well as driving economic and environment viability [5]. Local and regional authorities often face challenges by

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issues when applying the waste hierarchy approach. Other issues and concerns may involve:

- Waste management strategy implementation process with coherent process where it started at direct management without the property level of hierarchy.
- Lack of data available on waste management strategies must be overcome and extensive monitoring requirements must be met to successfully implement the waste programs
- Effective enforcement and control of sound business plans and practices be established and applied to maximize economic and environmental benefits.
- Lack of administrative capacity at regional and local level. The lack of funding, information and technical expertise must be overcome for effective implementation and success of policies, practices and procedures.

## II. RESEARCH METHODOLOGY

Reduce, reuse and recycle are recognised today around the world as an important principles of waste management strategy in order to prevent huge tipping fees due to the scarcity of landfill sites. The idea of 'reuse' and 'recycle' of many construction materials is a smart decision for all builders and/or demolition contractors, whether they are interested in environmentally-friendly building or not. Significantly, the direct reuse of building waste in its original state and/or slightly improved products often involves reprocessing of used materials into secondary of new materials. The success of recycling C&DW is determined by some key factors such as favorable construction site and location, proper resources and equipment, experience gain overtime by recyclers and contractors to determine the merits of individual materials, trained construction workers, market knowledge of secondary materials, financial implications and knowledge of environmental and legislative and control.

The objectives of the research were:

- To investigate construction waste recovery practices on site activities.
- To identify key challenges of adopting waste management in managing construction
- To identify the cost benefits of using secondary materials

Equation formulated for rate of reusing and recycling of C&DW is:

$$RR = RSM/TWP \tag{1}$$

where: RR is the Rate of Recovery of C&DW; RSM is the Real Secondary Material; TWP is the Total Waste Processed.

The rate of developing secondary materials indicates that waste management practices involving reusing and recycling construction waste in the two case studies (See Table II). Following the outcome of the equation adopted for individual material, '1' indicates fully development of secondary materials, '0' shows that all construction waste is to be diverted landfill. Theoretically, research shows that the value of rate of developing secondary materials is unswerving based on the articulated equation presented above. To investigate the reusing and recycling process for construction materials, two case studies are under investigation on costs and benefits in using secondary materials and the construction recovery process for five major types of construction materials: concrete, metal, wood, cardboard/paper and plasterboard. Data obtained from demolition specialist and contractors from Site A and B. the study consider two stage process.

First stage look at total waste processed for Site A and B as well as the outcome of construction material recycling and recovery process will be outline. Stage 2 focused on cost consideration for using secondary (reusable and recyclable) materials. Finally the study provides practical examples of the economics behind the development of secondary materials. Individual face-to-face interviews are arranged with each case study, including demolition contractors, site managers and supervisors, on-site construction workers. The involvement of all participants helps the field study to arrive at a more quality approach to reusing and recycling construction waste and helps determine the merits of individual materials in eth construction recovery process. Two personal interviews are arranged for each case study. First face-to-face interview focus on making clarity on research goals, visions, study details and data required. The second face-to-face interview focused on comments on data collected from Site A and B. The personal interviews are intended for obtaining additional comments, perceptions and views related to data required.

## III. RESULTS AND DISCUSSIONS

Tables I & II exemplify the 2012/2013 survey outcomes on the total waste processed % recycled, and % send to landfilled for five types of construction waste materials from the two case studies (Site A and B). As shown in Fig. 2, there is a large volume of concrete and wood waste from demolition works process and recycled in 2012 as compared to 2013. As show in the chart above, there has been a high percentage of all five construction waste materials been diverted to landfill in 2013 in Site A as compared to Site B. Also Site B has focused on recycling more wood and metal in 2013 due to available market for secondary material.

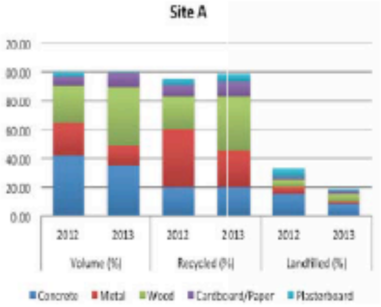

Fig. 2 Composition of mixed C&DW Debris (Case study 1)

TABLE I
COMPOSITION OF MIXED C&DW DEBRIS (CASE STUDY 1: SITE A)

| Recycling Operations at Site A | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2012 | | | | 2013 | | | |
| **Construction Waste** | **Volume (%)** | **Recycled (%)** | **Landfilled (%)** | **Construction Waste** | **Volume (%)** | **Recycled (%)** | **Landfilled (%)** |
| Concrete | 41.9 | 20 | 15 | Concrete | 35.09 | 20 | 8 |
| Metal | 22.86 | 40 | 5 | Metal | 13.92 | 25 | 2 |
| Wood | 25.71 | 23 | 5 | Wood | 40.2 | 38 | 5 |
| Cardboard/Paper | 6.19 | 8 | 2 | Cardboard/Paper | 10.37 | 10 | 2 |
| Plasterboard | 3.33 | 4 | 6 | Plasterboard | 0.41 | 6 | 2 |
| Total Waste | 100 | 95 | 33 | Total Waste | 100 | 99 | 19 |

TABLE II
COMPOSITION OF MIXED C&DW DEBRIS (CASE STUDY 2: SITE B)

| Recycling Operations at Site B | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2012 | | | | 2013 | | | |
| **Construction Waste** | **Volume (%)** | **Recycled (%)** | **Landfilled (%)** | **Construction Waste** | **Volume (%)** | **Recycled (%)** | **Landfilled (%)** |
| Concrete | 33.56 | 17 | 15 | Concrete | 27.01 | 15 | 6 |
| Metal | 17.54 | 22 | 5 | Metal | 15.05 | 25 | 0 |
| Wood | 27.06 | 35 | 5 | Wood | 38 | 42 | 0 |
| Cardboard/Paper | 12 | 15 | 2 | Cardboard/Paper | 19.08 | 12 | 2 |
| Plasterboard | 9.84 | 8 | 6 | Plasterboard | 0.86 | 6 | 1 |
| Total Waste | 100 | 97 | 33 | Total Waste | 100 | 100 | 9 |

TABLE III
RATE OF RECOVERY OF C&DW (CASE STUDY 1 & 2)

| **Case studies** | **2012** | | | **2013** | | |
|---|---|---|---|---|---|---|
| | **Total Waste Processed (Tonnes)** | **Real Secondary Material (Tonnes)** | **Rate of Recovery** | **Total Waste Processed (Tonnes)** | **Real Secondary Material (Tonnes)** | **Rate of Recovery** |
| **Site A** | | | | | | |
| Concrete | 880 | 820 | 0.93 | 835 | 775 | 0.93 |
| Metal | 480 | 480 | 1 | 345 | 232 | 0.67 |
| Wood | 540 | 120 | 0.22 | 945 | 912 | 0.97 |
| Cardboard/Paper | 130 | 60 | 0.46 | 102 | 19 | 0.19 |
| Plasterboard | 70 | 10 | 0.14 | 96 | 6 | 0.06 |
| **Site B** | | | | | | |
| Concrete | 820.54 | 789.34 | 0.96 | 940.06 | 856.23 | 0.91 |
| Metal | 325.37 | 300.76 | 0.92 | 143.06 | 143.06 | 0.69 |
| Wood | 940.04 | 923.06 | 0.98 | 1076 | 1076 | 1 |
| Cardboard/Paper | 242.56 | 98 | 0.4 | 114.56 | 79.76 | 0.7 |
| Plasterboard | 9.67 | 0.4 | 0.04 | 1.86 | 0.34 | 0.18 |

TABLE IV
MEASURES FOR 3R'S CONCEPT

| | **Reduction** | **Reuse** | **Recycle** | **Remarks** |
|---|---|---|---|---|
| **Concrete** | Precision, Accuracy in measuring amount of concrete needed according to organisation policy and procedure | Reuse concrete waste for minor works | Recycling concrete as aggregate for construction | n/a |
| **Metal** | Precision and Accuracy in cutting, welding and fixing to minimise waste | Reuse metal scraps | Recycle metal scraps and develop new products/secondary materials | n/a |
| **Wood** | Use alternative materials in substitute to wood (e.g. carbon fibre, aluminum, steel etc. Use modular/prefab construction units | Wood waste products such as props, pods, formworks etc. should be shored and reused for other construction works. Cutting waste should be keep at minimum | Wood can be recycled to demolition contractors and local recyclers | n/a |
| **Cardboard/ paper** | Minimize the use of cardboard paper, use alternative construction materials | Reuse cardboard/paper such as packaging | Recycle cardboard/paper to develop new products | Adopting environment-friendly paper |

Table III indicates the survey outcome on the rate of recovery of C&DW for five major types of construction materials for the case study (concrete, metal, wood, cardboard/paper and plasterboard). 'Plasterboard' measured low rate of recover for the each case study. The study also found that '0.04' outcome on rate of recovery of plasterboard in 2012 that indicates that 'plasterboard' is relatively low to develop a secondary material. The interviewed site manager explained that best practice to apply the 3Rs to many of the construction waste materials particularly concrete waste is to use prefabricated/modular construction methods rather than the traditional in-situ concrete process.

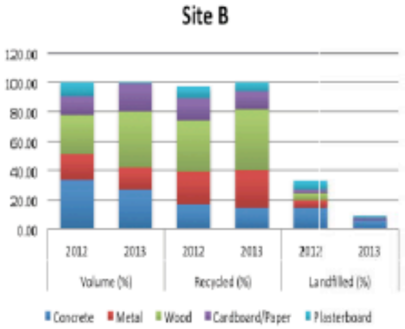

Fig. 3 Composition of mixed C&DW Debris (Case study 2)

An interview carried out with site demolition contractors and site managers revealed that plasterboard and cardboard/paper is very difficult to reuse and recycle on-site. Site manager for both Site A and B clarified that the lack of advance technology is responsible for the low recycling rate of plasterboard. The survey result also found that concrete, metal and wood have shown a high recovery rate [i.e. concrete range between 0.91 and 0.96; metal range between 0.67 to 1; wood 0.22 to 0.98]. This clearly indicates that there is a significant economic and environmental awareness on reusing and recycling concrete, metal and wood. Significantly, 'wood' has show an improved rate of recovery and it has proven to be more reusable for construction works and/or made available for secondary market.

The interviewed site manager made positive comments on 'wood' as a possible secondary material (reusable & recyclable construction waste). The site manager further explained that wood is easy to reuse and recycle with proper arrangement. Interestingly, interviewed site manager explained that there are key contributing factors such as supply and demand, legislation, incentives affecting the economics of recycling wood on construction sites. The market for wood waste varies according to region and its consumption in the UK has dropped sharply since 2007 from 12% to 6% in 2013 [4]. According to Tolvik report, UK wood waste increased by 4.3 Million tonnes and further increase in wood waste will be seen end of 2015 [4].

### *A. Cost Consideration for Recycling Operations*

Key issues with construction waste recover operations are the failure to perform a detailed cost benefits analysis at the early stage of business development. It is important for the recycling operations to carefully consider the stream of materials that will be flowing into the construction site in order to prepare the operation for processing the waste material into secondary materials with practically high value.

Tables I & II show a breakdown of the five constriction materials for each case study identified herein this study. It is obvious that the composition of C&DW varies from construction sites over time depending on the ration of commercial to residential construction as well as the proportion of demolition activities in the two construction sites. Traditionally, the diversion of C&DW gives income (tipping fees) by charging a fee for allowing waste to be transferred to landfill. This recycling gate fees coupled with the marketability of the byproduct as well as regulatory enforcement to control illegal dumping and properly manage landfills. The identification of a construction site for recycling operations and associated cost can be considered by applying recycling fee. However, it is imperative to fully define the aggregate selling price of secondary materials in such a manner that allows recyclers to compete against the cost of the raw material and more importantly provide adequate incentive for contractors to opt for managing C&DW.

#### 1. Costs/Benefits of Reducing Waste Example: A Case Study

Reducing, reusing and recycling waste can help to reduce costs on construction projects. Clients and contractors can secure best practice for waste minimization from an early stage in the design and planning process, can locked these savings and demonstrate corporate responsibility. Such action can be linked to corporate commitments in support of the target for halving waste to landfill. Case study identifies at design stage the costs and benefits through waste reduction and recovery in their construction activities. The main case study is a £1.5m redevelopment project of a new enterprise center. The project is to be constructed using steel frame, clad in mixture of brickwork, render and wood cladding. This project also involved external paving and landscaping, provision of car parking and an access road.

TABLE V
DESIGN POTENTIAL

| | **Value of materials wasted (£)** | **Cost of waste disposal (£)** | **Total cost of waste** | **Total cost of waste as % of construction value** |
|---|---|---|---|---|
| **Best practice** | 281,765 | 65,498 | 347,263 | 1.54% |
| **Good practice (all components)** | 122,623 | 24,266 | 146,889 | 0.65% |
| **Targeted practice (top opportunities)** | 155,880 | 30,785 | 30,785 | 0.83% |
| **Improvement over baseline** | **£125,885** | **£34,713** | **£160,598** | **0.71%** |

TABLE VI
CHANGE IN ENVIRONMENT PERFORMANCE

| | **Total waste arisings (t)** | **Waste sent to landfill (£)** | **Recover y rate** | **Carbon (t) 1** | **Recycled content** |
|---|---|---|---|---|---|
| **Baseline** | 1,264 | 561 | 55% | 1,180 | 20.50% |
| **Good practice** | 567 | 113 | 80.00% | 480 | 42.40% |
| **Targeted** | 671 | 135 | 80.00% | 522 | 32.80% |
| **Improvement over baseline** | **593 (47%)** | **426 (47%)** | **25.00%** | **658 (56%)** | **12.30%** |

This compulsory fee is considered as an income according to local jurisdiction. Interviewed site manager commented on cost benefits of developing secondary materials. This participant argued that the feasibility of introducing a new recycling facility is highly dependent of the interrelationship between the landfill-tipping fee and the targeting good waste reduction practice can make optimum saving in the value of material wasted. To complement the cost benefits, actions be demonstrate resource efficient also delivery key changes in environmental performance. Costs and benefits can be better understood in the case study in terms of waste reduction and recovery processes required to delivery-targeted savings. Achieving cost reductions (i.e. benefits) require to key perspectives: value of material wasted and cost of waste disposal.

Construction is considered as valuable resource and yet waste level of waste is seen considerably high. It is obvious that reducing this waste saves money. At the baseline, cost is £281,765 with targeted practice of £155,880 (improvement - 0.6% of construction value seen around £125,885 as indicated in Table IV). Cost of waste disposal is around £65,498 at baseline and £30,785 (improvement - 0.2% of construction value seen around a total of £34,713) can be substantially save cost simply by reducing quantity of waste generated. This savings is achievable by incorporating specific management actions to change behaviour during design phase. According to practical solutions to good practice for this case study an estimated £28,940 will be incurred to achieve savings of £160,598. The 'benefits' of using secondary material is considered alongside a reduction in value of materials wasted and reduction in cost of waste disposal. The *'costs'* needed to reduce waste or increase recovery' on the other hand is achieved by the contractor through planning and effective management.

## IV. RECOMMENDATIONS

To minimise construction waste generation, improve material recovery process there is a need for an effective coordination among construction professionals involved in the design and construction phase to coordinate waste management operations. Study suggests that the main contractor will predictably benefit from the reduction in the cost of waste disposal, but more benefits will be seen from waster reduction processes. To ensure that maximum benefit from good waste and best practices are realised and shared, it is therefore imperative for the client, the main contractor and the recycle specialist to work together. The paper advocate that on-site waste practices ought be effectively manage by introducing innovative tool-box workshops and sessions for all construction workers and demolition specialists, provide education on waste management to recyclers, project and site managers, develop innovative container types, segregate container and signage, accurate on-line reporting system.

To complement the rate of waste recovery process on construction sites there is a need to commendably consider the 3R's principle as a key guidance. A positive feedback from one of the participant interviewed reveals that concrete waste can be effective minimised if construction activities involving concrete work are greatly prefabricated units/panels. Significantly, the merits of reducing, reusing, recycling C&DW are emphasized, however the economic and environment impact are important to be considered in aspect of life-cycle assessments of construction waste materials. Although, satisfactory environmental awareness cannot be achieved in planned management support, however the legislative restrictions preventing construction and demolition waste stream from diversion to landfill still remains a bigger challenge globally.

## V. CONCLUSION

The success of C&DW recovery operations remains a key challenge as many municipals around the world. This process has great impact on the environment and the cost benefits within this process remain a positive outcome to all recyclers, demolition contractors, site managers and project managers. Construction activities remain a grand challenge as a result of consistent civil works, site clearing, demolition, and excavation. The properly functioning waste recovery operations process must earn much of its income from tipping fees and the sales of fully developed secondary materials. Sadly, the economics of recycling operations are not very favourable in most cases, waste recovery process is a complex process in the industry depending on materials to be reused, recycled and recovered. Recycling serves more to maintain positive outcomes on construction sites with diminished capacity to land.

Despite the extent of waste problem in construction, the available waste options such as reducing, reuse, recycle has swept the entire industry. Yet, the hurdles to meet global target to reduce unnecessary landfill of valuable materials that can be recovered and redeployed remain a grand challenge.

This paper investigated the costs and benefits in using secondary materials and focus on investigating reuse and recycling process for five major types of construction materials: concrete, metal, wood, cardboard/paper and plasterboard. It was found that 'concrete, metal and wood' have shown a high recovery rate. However, the costs and benefits for recovery these three materials are dependent on experience of end users. The content of this paper seems to be beneficial for different construction groups namely, demolition contractors, recyclers, on-site waste producers', aggregate users and other researchers.

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## Appendix 12

### Academic Paper 2

Oyenuga, A. A. and Bhamidimarri, R. (2015), “Economic Viability of Construction and Demolition Waste Management in terms of Cost Savings – A Case of UK Construction Industry”, Paper submitted *International Journal of Science and Engineering Investigations*

International Journal of
Science and Engineering Investigations
vol. 4, issue 43, August 2015
ISSN: 2251-8843

# Economic Viability of Construction and Demolition Waste Management in terms of Cost Savings - A Case of UK Construction Industry

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*Abstract*- The excessive building material waste, ineffective management on construction site, lack of data available on waste management strategies, lack of administrative capacity at local and regional level, ineffective enforcement and control of sound business plans and waste practices are common in some UK constriction sites. Today, in most European states, it is economically viable to recycle up to 80-90% of the overall C&D waste [21]. The rapid growth of the construction industry alongside complex activities have been responsible for the increase in the amount of waste generation which often result to the economic consideration in terms of cost-savings. With the increase in management and recycling operational costs and the lack of trained staff and expertise to undertaken appropriate measures to minimize waste, the UK construction industry faces a number of challenges in recent times. This paper aims to present the economic viability of applying the 3Rs principle to C&D waste in terms of cost savings in the UK construction industry.

***Keywords***- *Construction and Demolition (C&D) waste, 3R principle, Economic theory, Benefit-Cost Analysis (BCA), Site Waste Management (SWM), UK Construction Industry*

## I. INTRODUCTION

All over the world, waste may be generated during both extraction and processing of the raw materials as the construction industry consumes a significant amount of natural recourses and often generates large quantities of building waste. Rubbles and other waste and other building waste materials arise from construction activities like demolition, refurbishment works and new construction [1]. Construction is one of the largest sectors of the UK economy and contributed £103 billion in economic output, 6.5% of the total in 2014 as shown in Table 1 [2]. Interestingly, construction, demolition, renovation and refurbishment works account for around 100 million tonnes of waste in the UK each year.

Significantly, construction activities such as demolition, refurbishment and renovation projects generate mixture of inert and non-inert materials, which are predominately referred to as construction waste [3]. Materials resulting from construction and demolition of buildings and infrastructure constitute a significant amount (10-15%) of the total municipal solid waste stream [4]. The UK construction industry is a key sector for the UK economy. It contributes almost £90 billion to the UK economy (or 6.7%) in value added, comprises over 280,000 businesses covering some 2.93 million jobs, which is equivalent to about 10% of total UK employment [5]. The output from the construction sector is at around the 2005 level, and below output between 2006 and 2008.

TABLE I.

GROSS VALUE ADDED: SECTOR'S CONTRIBUTION TO THE UK ECONOMY

| Year | Table Column Head | | |
|---|---|---|---|
| | *£ billions (current price)* | *Real % change* | *% of economy* |
| 1997 | 43 | ... | 5.5% |
| 1998 | 47 | 1.5% | 5.7% |
| 1999 | 48 | 1.3% | 5.6% |
| 2000 | 56 | 0.9% | 6.1% |
| 2001 | 59 | 1.8% | 6.2% |
| 2002 | 66 | 5.7% | 5.7% |
| 2003 | 72 | 4.8% | 4.8% |
| 2004 | 76 | 5.3% | 6.8% |
| 2005 | 81 | 4.8% | 6.8% |
| 2006 | 86 | 5.3% | 6.8% |
| 2007 | 91 | -2.4% | 6.8% |
| 2008 | 90 | 0.8% | 6.9% |
| 2009 | 81 | 2.2% | 6.6% |
| 2010 | 84 | -2.6% | 6.0% |
| 2011 | 92 | -13.2% | 6.3% |
| 2012 | 89 | 8.5% | 6.0% |
| 2013 | 92 | 2.2% | 6.0% |
| 2014 | 103 | 9.5% | 6.5% |

Source: ONS, 2014

The construction industry is considered to be one of the largest in terms of economic spending, environmental impact, raw materials/natural resource usage, jobs creation and waste generation. With the increase in C&D waste generation through construction activities, the construction industry has been challenged with issues relating to economic and environmental impacts resulting from lack of waste minimisation techniques. The economic and environmental benefits expected from C&D waste minimization are relatively essential [6][7], since it provides key benefits to both the environment and the construction sector in terms cost savings. One of the key challenges to waste minimization is inability to devise proper management strategy in order to reduce or prevent construction waste stream. This paper aims to address the problem of C&D waste and management awareness, strategies, and current practice in the UK construction industry, further evaluating the economic viability of applying the 3Rs principle to construction and demolition waste in terms of cost savings.

## II. WASTE MINIMISATION – CURRENT PRACTICES

### A. *UK construction Industry*

Despite recent economic and financial crisis which affected most developed economies, the UK construction industry remains one of the largest in Europe, measured by job created, number of enterprises, and grow value added [8]. Table II below shows the value of construction sector according to type of work in Q1 2015.The private sector, including commercial sector were worth about £6.2 billion, which is about 30% of the total output. The cost saving potential in the UK runs for billions of pounds.

TABLE II.

VALUE OF CONSTRUCTION OUTPUT BY TYPE OF WORK

| Q1 2015 | | | |
|---|---|---|---|
| | | £ billions | % of total |
| **Private sector** | | 15.3 | 74% |
| | Housing | 5.6 | 27% |
| | Infrastructure | 2.5 | 12% |
| | Industrial | 1.1 | 5% |
| | Commercial | 6.2 | 30% |
| **Public sector** | | 15.3 | 74% |
| | Housing | 5.6 | 27% |
| | Infrastructure | 2.5 | 12% |
| | Other | 1.1 | 5% |
| **Total** | | 20.7 | |

Source: ONS, Output in the construction sector, 2015

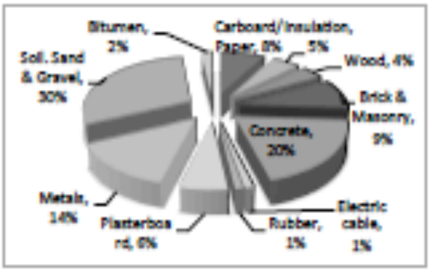

Figure 1: Waste streams at various stages of construction

Table II shows the distribution of cost among sectors in the UK construction industry. Both the private and public sector have increased in total output. The significance of materials cost indicates that major component of material cost, which is about 18% to 65% of the project cost. This shows that building material waste generation from construction activity is enormous in volume and in monetary terms. Therefore, there is a need for an economic evaluation of building material waste within the industry with appropriate waste minimization techniques.

TABLE III.

PROJECT COST DISTRIBUTION IN UK CONSTRUCTION INDUSTRY

| | Materials | Construction equipment | Labour |
|---|---|---|---|
| Housing | 65% | 9% | 15% |
| Infrastructure | 28% | 32% | 18% |
| Industrial | 38% | 25% | 20% |
| Commercial | 45% | 19% | 11% |
| Other | 18% | 8% | 8% |

Figure 1 and Table 3 show project cost distribution of C&D waste streams at various stages of construction in United Kingdom in 2014 [9]. The role of reducing waste is not just by the designer, the Government, contractors, subcontractors, suppliers, project stakeholders and client plays a huge role in ensuring better performance of managing construction waste. In practice, almost 8 out of 10 UK construction firms implemented or incorporated a many of proposed activities to reduce or minimize waste [10]. Thus, the segregation of waste, materials handling and improved storage methods were the most common initiatives were used by firms.

The UK construction industry spends over £200 million on Landfill Tax each year. Construction waste typically costs companies 4% of turnover with potential savings of 1% through the implementation of a comprehensive waste minimization program [11]. The UK Government adopt regulation, economic instruments and voluntary agreements to meet targets of ethical, social and environmental performance, pursuit for a step change in the sustainability of procurement, design, and operation of all built assets, to be driven by innovation [9]. It has been reported that 'waste accepted as inexorable'; lack of training, poorly defined responsibilities are underlying issues with designing was reduction in construction [12].

The separation techniques for most materials often attract advance technology options and legislative control with an underlying 3Rs waste management hierarchy principle. Waste management concept is guided by level of hierarchy explained by El-Haggar [13]. This model produces an integrated approach in which options of waste management can be considered and thus serves as a systematic tool for those who generate and manage waste [14]. El-Haggar [13] argued that when waste is being managed effectively it could generate various benefits through the wholelife cycle of the waste from its generation to its end disposal. Significantly, it is believed that proper construction waste management will provide both economic and environmental benefits. A number of construction firms as well as the environment at large will benefit through the cost reduction process involved in waste management.

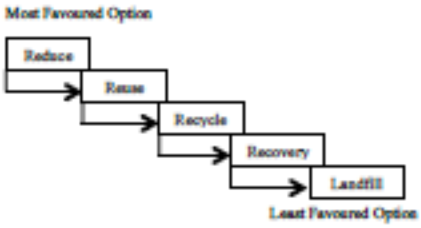

Figure 2: Waste Management Hierarchy (Source: El-Haggar, 2007 – Sustainable Industrial Design and Waste Management)

The economic and environment benefits expected from waste minimization are relatively essential as it drives towards the opportunity seen in recycling and the possibilities of selling secondary waste materials as well as the meeting targets on reducing the number of C&D waste being diverted to landfill [14]. Although the transfer of waste to landfill often attracts associated fees/charges and this can be minimized if only waste stream from construction are effectively managed.

### *B. Construction Waste Reduction Approaches in the UK*

Waste minimization in the UK is not a new approach to the construction industry. Waste management in the UK involves understanding and complying with a list of legislation and regulations. The EU Waste Framework Directive provides the legislative framework for the collection, transport, recovery and disposal of waste, and includes a common definition of waste [16]. According to Osmani [9] the current practices in the UK for waste reduction can be broadly categorized into the following and not limited to:

- Construction waste quantification and source evaluation
- Procurement waste minimization strategies
- Designing out waste
- On-site construction waste sorting methods and techniques
- Development of waste data collection models, including flows of waste and waste management mapping, to help with the handling of on-site waste
- Development of on-site auditing and assessment tools
- Impact of legislation on waste management practices
- Reuse and recycle in construction
- Waste minimization manuals, including guides for designers.

The above lists indicate strategies to promote awareness of benefits of waste minimization in the construction industry, including cost savings, and environmental impact and use of secondary (recycled/reclaimed) materials. Interestingly, legislative and fiscal measures are undoubtedly the major driver for construction waste reduction in the United Kingdom, which were directly related to the rising Landfill Tax, increasing cost for waste disposal, and adhering to the Site Waste Management (SWM) Regulation 2008. Sadly, the current legislation fails to impose responsibilities on architects to minimize waste, which is by far most practical way to reduce waste at early design phase, rather than implementing waste minimization measures later on during construction phase [12].

## III. PROBLEMS WITH WASTE MANAGEMENT IN CONSTRUCTION INDUSTRY

The UK construction industry has been faced with many challenges to successfully implement waste management strategies in terms of ineffective management on construction site among others. However, the economic benefits in terms of cost savings are still limited. The following key barriers were identified in a few studies found in literature, Osmani [10], Hansen et al. [17] and Saez et al. [18]:

1. *Ineffective management on construction site*: despite the introduction of the SWM regulation 2008, ineffective management on construction site continues to affect the building material performance. A few construction projects are yet to conform to the waste management regulation and not effectively managing their overall waste generated from construction works [18].
2. *Lack of data available on Waste Management Strategies*: the major barrier in construction industry is the lack of appropriate data and awareness of local contractors on waste minimization techniques. This often result to poor waste handling on site [18]. A coherent waste management strategy that must be set up and implemented. It would involve including management plans at all different management levels.
3. *Lack of administrative capacity at local and regional level*:

   The legislative competence and the physical responsibility fro each task of waste management within a country both at local and/or national level must be clearly delegated. Regional and local authorities mainly responsible for planning, enforcement and control, often are not able to fulfill their tasks adequately because of lack of administrative and/or monetary capacity. Transparency and public participation must be enriched [17]. The task of implementing the waste hierarchy in waste management practices within a country must be clearly delegated to the different levels of government (national, regional, local) and to other possible actors including industry, and private companies. The lack of finances, information, and technical expertise must be overcome for effective implementation of waste management policies and practices.

4. *Ineffective enforcement and control of sound business plans and waste practices*: ineffective enforcement of waste management legislation and the development of a realistic business plans and best practices continue to create greater challenges for local authorities and contractors [17].

5. *Poor defined responsibilities and lack of training*: poor defined responsibilities in designing out waste remain greater challenge for the UK construction industry. This is simply means should not be accepted as inevitable for designers such as architects to design in waste reduction measures in many construction projects. Adequate training facilities for designers, contractors, subcontractors etc. must be employed [10].

The UK Construction industry has contributed positively to waste minimization over the years [11]. The 3Rs (reduce, reuse, recycle) principle has been wide employed to achieve a successful waste minimization process within the industry. However, the impact of the waste management legislation particularly, the Landfill Tax, and its effects on waste practices in the industry have raised a number of controversies in recent times [11]. Significantly, management tool such as SMART Waste developed in the UK have helped the construction industry to effectively handle and better manage on-site waste generation and assess the linked cost-saving implications. The SMART Waste tool facilitate on-site auditing, waste management, and as cost analysis for known waste stream.

Thus, the UK Government has introduced a landfill tax, aggregate levy and other waste management regulations that encourage the diversion of waste from landfill, promote reuse and recycle strategies, and emphasise environmental responsibility. Further measures are needed in terms of cost-savings for reuse and recycling operations if the construction industry is to realize waste minimisation as part of its core activity [19]. The ultimate cause of waste are due to design issues, however, key contributing factors such as procurements, handling of materials and construction operations [20]. There is a need for the construction industry to understand these key factors and be able to mitigate the extent of the problem by evaluating the cost saving potential in managing C&D waste on site.

## IV. SIGNIFICANCE TO ECONOMIC MODEL

### A. *Economic viability in terms of cost savings*

The economic viability of C&D waste handling on construction site is investigated and evaluated in this section. This section focused on justifying how the cost saving potential can be achieved in the construction industry. It is important to understand the economic model and its significance to achieving the economic feasibility of managing C&D waste. Economic model, however, provides an outlet for research in all areas of economics based on rigorous theoretical reasoning and on topics in mathematics that are supported by the analysis of economic problems [21]. However, the conventional economic feasibility in terms of cost-savings of handling construction waste is often carried out by a standard measure of profitability derived from a Benefit-Cost Analysis (BCA)[22].

BCA is considered for this study to estimate the economic viability of C&D waste handling on construction site. The study attempt to evaluate overall project cost, amount of waste generation, sources, waste composition and the cost of reuse and recycling of C&D waste. A few studies argued that argued that the economic impact of recycling can be measured through industrial output, total income, value added and number of jobs created [22-23]. The study estimated the net benefits to evaluate the economic viability of reuse and recycling of C&D waste on the project site. The net benefit can be expressed using economic theory by Eq. (1):

$$N_B = T_B - T_C \tag{1}$$

Where $N_B$ is the net benefits, $T_B$ the total benefits and $T_C$ is the total costs. The total benefits ($T_B$) are all the advantages of reusing and recycling of C&D waste. This is considered the sum of all direct, indirect and intangible benefits. Thus, the total benefits can be expressed further in Eq. (2)

$$T_B = P_{CS} + T_{SM} + CS_{WCT} + CS_{LF} + I_B \tag{2}$$

Where $T_B$ is the total benefits of reusing and recycling of C&D waste on the site, $P_{CS}$ the purchasing costs savings by reusing an recycling of C&D waste, $T_{SM}$ the turnover from selling of scrap C&D waste materials, $CS_{WCT}$ the waste collection and transportation cost savings by reusing and recycling of C&D waste, $CS_{LF}$ the cost savings from landfill fees by reusing and recycling of C&D waste, and $I_B$ is the intangible benefits. The total costs are all the incremental costs associated with the reusing and recycling of C&D waste. This is the sum of all direct and indirect and intangible costs respectively. Total costs can be expressed by Eq. (3)

$$T_C = CS_C + EP_C + S_C + T + I_C \tag{3}$$

Where $T_C$ is the total costs of reusing and recycling of C&D waste on the site, $CS_C$ the collection and separation costs of C&D waste, $EP_C$ is the equipment purchasing costs, $S_C$ is the storage costs, T the transportation cost od disposing waste to landfill and $I_C$ is the intangible costs. The economic feasibility of a recycling program often depends on whether the added cost (time, effort and resources/equipment) associated with the recycling activities is less than the avoided costs (tipping fees, labor, haulage, maintenance, taxes, and local permanent fees) as shown in Eq. 4 below [4; 24].

$$N_B = T_B > T_C \tag{4}$$

Company can engage in cost-savings by reusing and purchasing recycled building material rather than buying virgin building materials from the market [22]. Purchasing costs savings is very essential in quantifying cost benefit for C&D waste. Therefore, if any construction company could not reuse and recycle building waste materials it would be needed to buy those materials. The study found out that estimated purchasing cost savings for C&D waste is the sum of the cost saving from materials market price and the transportation cost savings expressed in the Eq. (5) below

$$P_{CS} = CS_{MP} + TCS \qquad (5)$$

Where $P_{CS}$ the purchasing costs savings by reusing and recycling of C&D waste, $CS_{MP}$ the cost saving from market price and TCS the transportation cost saving. The study shows that waste minimization is economically viable and also plays a key role for the improvement of environmental management. The economic determinant of recycling operations lies within this context, as cost remains a key aspect of choices for best practices for waste minimization. Outcome of the study shows that cost of handling waste practices is considered highly than its benefits. However, evaluating all monetary terms for physical benefits and associated costs for intangible items provides the economic viability of C&D waste handling on construction site. In performing BCA of waste minimization using the 3Rs principle, all the benefits and associated costs are carefully considered.

The study attempted to measure all benefits and costs in terms of monetary value as well as those costs and benefits with non-monetary value, which is described above as tangible benefits ($I_B$) and intangible costs ($I_C$). Total benefits consist of both the direct and indirect benefits relating to purchasing costs savings ($P_{CS}$) and waste collection and transportation cost savings ($CS_{WCT}$) respectively. We argued that waste practices have many cost-related challenges in terms of improper planning, lack of incentives, designing out waste at the early stage of project. However, a number of approaches have been proposed over the years to mitigate the impact on waste generation. To address the underlying cost-benefit issues and to promote waste minimization in many construction sites the following strategies are discussed.

## V. STRATEGY TO ADDRESS THE PROBLEM

Investigating the ineffective waste management practices on construction site, this aspect of the research study suggests appropriate strategies that can be used within the industry to address the extent of problem at hand. The cost-saving potential relating to waste minimization within the industry remains a key measure to justifying the economic viability of C&D waste handling on construction site.

### *1. Effective Co-ordination – Partnering and Collaboration*

To minimize waste generation, improve building material recovery process, there is a great need for construction professional to work in partnership and ensure information sharing within their network. Study suggests that contractor will benefit from waste reduction in the cost of waste disposal, rather more benefits will be seen from waste minimization perspective if partnering is encouraged. There is no unified view as to what partnering relationships are in the construction industry. A few studies have supported this concept as an approach to improve construction industry [25; 26; 27].

The definition of partnering in construction was cited in these studies as a long-term commitment between two or more parties in which shared understanding and trust development for the benefits of improving construction. Despite great interest, efforts to implement the partnering concept in the construction industry are yet to yield the positive effects that have occurred in other industries [28]. This perceived underperformance is as a result of the tendency to focus on mutual relationships between, clients, contractors, designers, sub-contractors and suppliers [29]. To ensure that optimum benefit from 'zero waste' and best waste management practices are achieved, the supply chain in construction should consider 'partnering' as a robust approach to mitigate the problem.

### *2. Designing Out Waste – Role of a Designer*

Designers such as architects, civil engineers, technicians are required to design building following guidance from the WRAP "design out waste" [11]. Designers should consider standard sizes, densities, positioning and height to enhance the process of waste minimization and primarily to achieve cost savings in construction. Recyclable building materials are required to be incorporated in design at the early phase of design and construction. Architects have a major role to play in providing the right specifications when designing out waste. This approach presents a proactive target options to reduce waste, recognizing that some key solutions on a project are most likely to achieve waste minimization, along with cost savings, carbon reduction and other related benefits.

### *3. Enforcement and Incentive – Robust Policy Implementation*

Addressing the lack of enforcement and local control should start from Government's intervention in ensuring waste management legislation is put into practice. The UK Government should provide a robust approach to implementing the waste management legislation. Although, the EU Waste Framework Directive have been a start-point to EU environmental concern and effective management of waste across it states, the UK however derived its legislation from this framework. Study suggests that the UK government should carefully consider sustainability in this context in order to ensure that citizens understand the benefits of the 3Rs principle across all industry-sectors not just in construction at a whole.

Other aspect of policy implementation is the introduction of landfill tax to promote waste minimization and lack of incentives for producing secondary materials (reusable and recyclable materials). There is a need for the Government to design a Tax credit for firms who create secondary materials (recycled building products) directly on-site or off-site. We study suggests that the Government should revise the Landfill Tax regulation 2013 and develop provisions for substantial incentives for the construction industry to embark more on recycling operations and reduce the rate of waste stream being diverted to landfill. The Government plays a major role in major in ensuring the construction industry improves amount of C&D waste at its source.

The development of the Site Waste Management Plans and other legislation such as Energy Performance of Building Directive, UK Climate Change Act 2008, and Environment Impact Assessment are tested tools to provide a better waste handling on many construction sites. However, the construction industry faces key challenges such as improper management execution and attention to detail on economic and environment impact with waste generation. We believe that the introduction of Tax credit for recycled materials will further create incentives for many local contractors and recyclers. Developing robust policy context will help create awareness on economic benefits of reusing and recycling C&D waste.

*4. Education and Training*

Lack of training and education to promote waste minimization remains a major challenge facing the UK construction industry. Since the introduction of the SMART Waste tool in the UK, there is a need for education and training to unskilled labour and other construction professionals to gain knowledge on waste minimization and the need for cost-savings as well as environment impact. Therefore, the many construction firms has the duty of care and the responsibility to ensure their workforce are fully educated and trained to handle waste directly on and off construction sites. Training in construction is introduced to improve skills, increase competitive edge and respond to many challenges employers face [30].

*5. Access to Information – Waste Management Strategies*

Lack of data available on waste management strategies continue to affect a number of small construction firms in the United Kingdom. A lack of data available on waste management strategies must be overcome and extensive monitoring requirements must be met to successfully implement the waste minimization initiative. Access to information often helps a number of project stakeholders; client, contractors, sub-contractors and suppliers understand the business case for waste minimization program.

## VI. IMPLICATION TO PRACTICE

The proposed strategies can help the construction industry in a number of ways in terms of cost-savings and environmental impact. However, managing C&D waste has become one of the major environmental problems in the world. The proposed strategies to mitigate this problem are stated in this study. The study further suggests that the Government and other project stakeholders should continue improving waste minimization on construction sites. Significantly, the introduction of 'tax credit' will further encourage local contractors, recyclers, and aggregate users to consider secondary (reusable and recyclable) materials as a better option.

Waste minimization technique help reduce the significant quantities of construction waste sent to landfill and encourage cost-savings for both economic and environmental benefits. More efficient use of building material would make a major construction to reducing the environmental impacts of construction including reducing demand for landfill and the depletion of finite natural resources [11]. Major improvements in building materials efficiency are possible without increasing costs by minimizing the overall creation of waste resulting from inefficient design and also reducing the quantity of material sent to landfill.

Clients, project stakeholders and contractors can secure best practice for waste minimization from an early design stage in construction in terms of cost savings and demonstrating corporate responsibility throughout the construction lifecycle. However, the benefit derived from cost-savings through waste minimization practices provides many local contractors the opportunity to recycle market where waste can be seen as a resource.

## VII. COST/BENEFITS OF REDCUING WASTE: A CASE STUDY

Waste minimization is known as a primary focus for most waste management strategies. Reducing, reusing and recycling waste can help to reduce costs on construction projects. Achieving the costs and benefits of reducing waste in construction can be achieved through good practice from early design and planning stage. The current case study identifies project at design stage, the costs and benefits achieve through waste reduction and the recovery on a construction project.

The case study is a £23m new build concrete-frame office with plant room and lower ground floor parking. The project is constructed using substructure, frame, floor, roof and external walls is a block work inner skin with aluminum rain-screen cladding. Significant savings can be made by targeting good practice wastage rate for the 10+ components offering the biggest savings in the value of materials wasted. The cost-saving potential below will be shared across the supply chain where client and principal contractors can increase their share through the procurement process.

TABLE IV.

DESIGN POTENTIAL

| | Value of materials wasted (£) | Cost of waste disposal (£) | Total cost of waste | Total cost of waste as % of construction value |
|---|---|---|---|---|
| Best practice | 202,072 | 45,043 | 247,115 | 1.07% |
| Good practice (all components) | 94,235 | 19,228 | 113,463 | 0.49% |
| Targeted practice (top opportunities) | 100,350 | 20,976 | 121,325 | 0.53% |
| **Improvement over baseline** | **£101,722** | **£24,067** | **£125,790** | **0.55%** |

TABLE V.

COST/BENEFITS SUMMARY

| **Achieving cost reductions (BENEFITS)** | **Baseline** | **Targeted practice** | **Improvement** |
|---|---|---|---|
| **Value of materials wasted:** construction materials are a valuable resource, yet it is common to see high levels of waste through damage on site, off-cuts, over-ordering of materials and the need for rework | **£202,072** | **£100,350** | **£101,722** (0.4% of construction value) |
| **Cost of waste disposal:** Every skip or container of waste carries a cost. Whilst segregated metals are often removed at little or even zero charge, the majority of wastes carry substantial costs - and these are set to rise with the annual increase in landfill tax | **£45,043** | **£20,976** | **£24,067** (0.11% of construction value) (£20,672 saved through reduced waste arising and £3.95 saved through increased segregation) |
| **Combined savings** | | | **£125,790** |

At the baseline, cost is 201,072 with targeted practice of £100,350 (improvement - 0.4% of construction value). Cost of waste disposal shows £45,043 at the baseline, targeted practice of £20,976 with an improvement of 0.11% of construction value. Table V shows that about £20,672 saved through reduced waste arising and £3,395 saved through increased segregation. The cost saving potential achieved as a result of management strategies to designer's approach to design waste at the early stage of construction. Practical solutions to good practice for the current case study indicated that £20,672 is incurred in order to achieve cost savings of £125,790. The benefits of using recycled materials are achieved by cutting down construction material value wasted and the reduction in the cost of waste disposal.

On the other hand, the cost required to cut down waste or enhance material recovery is determined by experience of contractors, aggregate users and recyclers during planning and waste management strategies implementation. However, building materials provide the largest cost reduction potential and demonstrate good practice at baseline. The potential cost saving for the reduction in value of materials wasted (i.e. £101.722) justifies the cost of waste minimization and management. The study suggests that designers need to look for opportunities to design out waste, contractors need to develop a quality SWMP and a materials logistics plan as well as the ensuring that all waste received are recycled wherever possible.

## VIII. CONCLUSIONS

With the success of waste minimization techniques in many construction site, there are still some challenges found with management with the UK construction industry. These problems have both economic and environmental impact as clients, contractors, recyclers, aggregate users and others are striving to address the extent of the problem. Scrutinizing a number of reasons for the problem, excessive building material waste, ineffective management on construction site, lack of data available on waste management strategies, lack of administrative capacity at local and regional level, ineffective enforcement and control of sound business plans and waste practices are few of a number of reasons that considerably affect the construction industry as a whole.

The economic viability of managing C&D waste on construction site can be justified by the cost-savings potential in many cases. However, by understanding of proper waste management, the total benefits will continue to exceed cost associated to waste operations as a whole. The paper investigated the problem of C&D waste and management awareness, strategies, and current practice in the UK construction industry, and extended study scope to evaluate the economic viability of applying the 3Rs principle to construction and demolition waste in terms of cost savings.

The study found out that net benefit of reusing and recycling of C&D waste is estimated at a significant amount of total project budget. Realistically, the UK construction industry can, in fact, save money by implementing waste minimization practices using 3Rs principles in managing wastes on construction sites.

## ACKNOWLEDGMENT

The authors would like to acknowledge the suggestions of the editor and three anonymous academic reviewers

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## Appendix 13

## Academic Paper 3

Oyenuga, A. A. and Bhamidimarri, R. (2015), “Considering Appropriate Decision Support Models for Construction and Demolition Waste Management Optimization: Possibilities and Limitations”, Paper submitted to SSRG *International Journal of Economics and Management Studies (SSRG-IJEMS) 2(5)*

# Considering Appropriate Decision Support Models for Construction and Demolition Waste Management Optimization: Possibilities and Limitations

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***Abstract*** — *Significant number of modelling tools and methods that can be used for decision-support on C&D waste management at various levels have been developed. Examples of available management tools include Cost Benefit Analysis (CBA), Life Cycle Assessment (LCA), Risk Assessment (RA), Material Flow Analysis (MFA), Multi-Criteria Decision Analysis (MCDA), Decision Support Systems (DSS), System Dynamics (SD) and other types of optimizing models etc. Diverse range of different waste management methods that are available may be unclear or rather too complex to use. There is a growing concern and an urgent need to consider the appropriateness and attributes of using different waste management tools in different scenarios are required. Thus, the attributes considered in this paper focused solely on impacts categories and the entity under study. This paper focused on providing practical guidelines for selecting appropriate models for C&D waste management optimization and also finds a broader understanding of the opportunities and limitations with available modelling tools in order to achieve a realistic and a more sustainable decision-support approach to C&D waste management.*

**Keywords** - *construction and demolition (C&D) waste, decision support system, cost benefit analysis, life-cycle assessment, multi-criteria decision analysis, waste management*

## I. INTRODUCTION

Globally, construction/demolition industry is considered one of the largest producers of solid wastes [1]. Over the years, C&D waste issues have received increasing attention from both practitioners and researchers around the world. Construction waste seems to have caused serious environmental problems in many large cities around the world over the past decades [2]. Significantly, C&D waste is generated from huge amounts of new build, renovation works, infrastructure and civil works which have been undertaken over the years as demolition of existing structures became more necessary [3]. Thinking about waste management from a limited perspective often result to environmental, economic and social concerns. This is because a significant amount of greenhouse gas emissions, time and monetary value are incurred on transporting, processing, recycling, reusing and disposal in landfill. Therefore, there is a need for a properly managed waste system to be established by considering appropriate waste management models.

A significant number of management theories, methods, approaches and modelling tools that can be adopted for decision support on C&D waste at various levels have been developed [4]. Some of these focused on the economic impact of C&D waste management systems in terms of recycling and reuse of C&W waste (e.g. Economic Theory, Equilibrium model, Cost-Benefit Analysis and Life Cycle Costing etc.) Other management tools concentrate on the environmental impact of C&D waste management systems (Life Cycle Assessment, Multi-Criteria Decision Analysis, Analytic Hierarchy Process etc.).

A wide range of different waste management methods that are available may be ambiguous and there is an urgent need to consider the appropriateness and attributes of using different tools in different situations. There is a growing interest in developing sustainable waste management models as these raise major concerns in the decision-making process [2]. Thus, decision support models often help policy makers to select and design sustainable and cost-effective waste management systems [5, 6]. A number of decision support models for C&D waste management can be found in literature [7, 8, 9, 10, 11, 12, 13, 14]. For example, the review of Calvo et al. [9] considers the Environmental Management System (EMS) based on regulation impact and economic incentives to develop 3Rs concept.

Bani et al. [4] reviews the development of decision support systems (DSS) and added that the various elements in developing the DSS must be integrated and optimized in order to produce a feasible model that is marketable and has practical application. Achillas et al. [8] on the other hand developed an inventory of decision processes based on multi-criteria decision analysis (MCDA) for different waste systems. Karmperis et al. [14] take a holistic view and discuss the decision support models commonly used in the solid waste management system. In Karmperis et al. [13] study, the authors closely examine the strengths, weakness and critical issues with four decision support models, which are the cost-benefit analysis (CBA), the game theory (GT), the life-cycle assessment (LCA) and the multi-criteria decision analysis (MCDA). The study concludes that the development of the bargaining game theory directly leads to all three pillars of sustainability (i.e. economic, environmental and social) and that two key areas such as optimal location of waste processing plant and optimal management strategy remains a central focus of the study.

Today, most available decision support models are getting increasing recognition in resolving complex solid waste problems. Yet, most these models are considered too complex and ambiguous in its capacity to demonstrate appropriateness and reliability during application. It is therefore imperative to find an understanding of the possibilities and limitations of available management models. This paper presents a review of available management tools and provides some valuable insights into selecting appropriate decision support model as well as discussing some key opportunities and limitations to the application of available waste management tools.

## II. A REVIEW OF WASTE MANAGEMENT TOOLS

A significant number of waste management tools for assessing both economic and environmental impacts are available [15, 16, 17, 18]. Individual attributes for available tools are considered in this review as the study present an overview of management tools within the field of waste management. Thus, the attributes that will be used in this paper are the types of associated impacts and the entity under study. We intend to determine whether or not each available management tool can be classified as practical or systematic. Practical tools focus on hands-on procedures and links to its decision and social context. On the other hand, systematic tools focus on the technical aspects of the actual analysis [19]. Arguably, practical tools can be adopted within the framework of systematic tools [20].

Within the context of environment impact of waste management, both Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) are known and considered as practical tools. The EIA tool is used to predict the environmental consequences (positive or negative) of a plan, policy, program or project prior to the decision to proceed with the proposed action [21]. EIA is considered as a location-specific tool as compared to other management tools [22]. With this regard the project site locations and the greenhouse gas emissions are identified as EIA tool is commonly used to evaluate individual locations. SEA tool on the other hand is used to ensure that the environmental consequences of plans or programs (i.e. land use, traffic planning, site waste management planning etc.) are identified and gauged [23].

The SEA tool is used at the early stage of decision making for solid waste management. Both EIA and SEA are commonly known to be practical tools for solid waste management as compared to other systematic tools such as Life Cycle Assessment (LCA) and Risk Assessment (RA), which directly key parts of SEA process [24]. Thus, the use of SEA tool in waste management context is limited and it is often used for voluntary basis in few cases due to its practicality [23]. Examples of systematic tools are life cycle assessment (LCA), cost-benefit analysis (CBA), risk management (RA), multi-criteria decision analysis (MCDA) etc. Scholars at national and international level have made researches on C&D waste management economic and environmental impact [24, 25, 26], for example,

Banar et al. [27] use LCA tool to determine the optimum municipal solid waste by developing five different scenarios as alternatives to the current waste management system. Collection and transportation of C&D waste, a material recovery facility, recycling, composting, incineration and landfilling processes were considered in these scenarios as policy alternatives are investigated against associated environmental impact. LCA tool is often used to investigate the potential environmental impacts, throughout a product's life (i.e. from start to finish) [27]. The LCA methodology was first developed by ISO standard by considering four phases, namely, goal and scope definition, inventory analysis, (input/output), impact categories and interpretations [27]. Ulukan and Kop [13] conducted multi-criteria decision analysis (MCDA) of solid waste collection methods using LCA outputs. In this study, different solid waste collection methods are compared with fuzzy TOPSIS method, according to three pillars of sustainability (economic, social and environment criteria). This study limits measurement to economic and social and neglect environment criteria; however, the study further evaluates the environmental impact with the help of LCA.

**TABLE I**
LCA VS. MCDA MODEL

| LCA | MCDA |
|---|---|
| Use to understand trade-offs | Trade-offs and other complex issues |
| Systematic environmental management tool that analyses and assesses the environmental impact of a products/ process | Considers real world decision-making problems due to its complexities. |
| Use weighting factors to calculate LCIA | Use objective and subjective mapping to determine choice-based decision |
| Collects, organises, and evaluates quantified data useful for decision-making | Establish preference between options by reference to an explicit set of objectives that the decision making body has identified. |
| Decision-support system (sometimes evaluation are unclear enough to serve the purpose of comparative LCAs). | Clear and transparent methodology for decision-support system |
| Enables modelling, evaluation and comparison of different alternatives of products | Analyse the results of LCA of products. MCDA can be used to interpret LCIA |
| Evaluate decision on economic and environment impact | Use for analysing difficult scenario on environment impact such as Global Warming Potential (GWP), Human Toxicity Potential (HTP) etc. |

The MCDA considers real world decision-making problems due to its complexities. The multi-criteria decision analysis has become a tool commonly applied to building waste management, allowing decision-makers to have deep understand of the problem, and suppliers alternative courses of action, from several viewpoints [28, 29]. Table I shows the comparison between LCA model and MDCA model. It is significantly beneficial to combine LCA with MCDA model in order to simplify basis understanding of trade-offs and multiple perspectives in the impact assessment [30].

**TABLE II**
ARRANGEMENT OF LITERATURE ON DECISION SUPPORT TOOLS FOR C&D WASTE MANAGEMENT

| Authors | Type of decision support | | Assessment Criteria | | | Modelling Orientation | |
|---|---|---|---|---|---|---|---|
| | Location - Specific | Treatment Systems/ processing | Economic/Financial | Social | Environment | Optimization | Universal decision support |
| Chen et al. (2002) | | x | x | | x | x | |
| Begum et al. (2006) | x | x | x | x | | x | |
| Duran et al. (2006) | x | x | x | | | | x |
| Hao et al. (2007) | x | x | | | | | x |
| Bani et al. (2009) | | x | x | x | x | x | x |
| Ulukan and Kop (2009) | x | x | x | | x | x | x |
| Bilec et al. (2010) | | x | | | x | x | x |
| Milani et al. (2011) | x | | x | x | x | | x |
| Boufatech et al. (2011) | x | x | | | x | x | x |
| Achillas et al. (2013) | | x | x | x | x | x | x |
| Coelho and De Brito (2013) | x | x | | | x | | |
| Karmperis et al. (2013) | | x | x | x | x | x | x |
| Calvo et al. (2014) | x | x | x | x | | x | x |
| Abdelhamid (2014) | x | x | x | | x | x | x |
| Chang and Pires (2015) | | x | x | x | x | | x |

Milani et al. [30] conducted a multi-criteria decision making with life cycle assessment for material section of composites. This model is designed to deal with decision conflicts often seen among design criteria in composite material selection with the help of LCA methodology. The study found that simple MCDA model fully support trade-offs and design break-even points in large decision spaces as the decision maker's perspective over environmental, material performance and cost characteristics change during the design process. With the opportunities found with MCDA model, we found guidelines for selection of MCDA in literature [13, 31, 32]. Table III shows the guideline considered for the selection of MCDA tool.

TABLE III

GUIDELINE FOR SELECTING APPROPRIATE MCDA MODEL

| hecklist for ICDA nodel | Guideline |
|---|---|
| ✓ | Determine the stakeholders of the decision process. |
| ✓ | Consider the cognitive nature of decision makers when choosing a particular preference clarification mode. |
| ✓ | Determine the key issues with decision identified by decision makers. If they will like to get an alternative ranking, then a ranking method is considered. |
| ✓ | Choose the multi-criterion aggregation (MCAP) procedure that can accurately accommodate the input information available for which the decision makers can easily give the required information |
| ✓ | The compensation degree of the multi-criterion aggregation procedure is an important aspect to consider and to explain to decision makers if he/she refuses any compensation, then MCAP will be rejected. |
| ✓ | The fundamental hypothesis of the method I to be met (verified), otherwise one should choose another method |
| ✓ | The decision support system which comes with the method is an important aspect to be considered when the time comes to choose a MCDA method |

It is important to understand that these listed guidelines help many decision makers to evaluate the appropriate type of analysis suitable for the difference scenarios. Table II summarizes the key findings of the literature review. Universally, decision support for C&D waste management focus only on a few of the aspects listed in Table II. It is important to understand that decision support is based on complex estimation with the help of mathematical expression, assumptions, variables considered to be location or region-specific. The criteria used for selecting each potential treatment technologies are classified under four main groups: environmental and health performance, economic viability, technical efficiency and social acceptance [31]. Milani et al. [30] suggested that waste management treatment/processing using varieties of technologies should be able to assess the quality and quantity as well as the climatic conditions of individual location under study. Simonetto and Brenstein [33] develop a unique decision support model approach for solid waste management system flow. This paper focused on the conception, modeling, and the implementation of decision support system to the operational planning solid waste collection system. The system developed in the study attempt to generate alternatives to decision on allocation of separate collection vehicle and their travel distances as well as the determination of the daily amount of solid waste diverted to sorting facilities. The study suggests that full optimization process can be achieved if thorough investigation focused on reducing the amount of solid waste sent to landfill, assuring a waste input percentage at each sorting facility, estimating the work capacity of sorting facilities, assigning vehicles to collection trips, and finally defining their travel distances [33]. Other management tools include cost benefit analysis, risk management and material flow analysis, which a further discussed in this study.

Begum [34] carried out cost-benefit analysis (CBA) of on-site C&D waste reuse and recycling in Malaysia, by the statistical method, he pointed out that the total revenue of on-site C&D waste reuse and recycling operation is unruffled of the saved items such as: collection and transportation cost, purchasing cost, landfilling cost, sales income, separation costs, equipment costs, storage cost, and other tangible and intangible costs and benefits [34]. In contrast, Tam [35] carried out cost-benefit analysis on concrete waste disposal and recycling in Australia, by accounting and statistical method, and found that recycling concrete waste is more cost effective than disposal to landfill. CBA is commonly known as a systematic tool for assessing the total costs and benefits from a planned project. It is also known as a decision support tool that helps in defining scenarios for the feasibility of reuse and recycling C&D waste [34]. A number of economic assessments are carried out on a regular basis. Economic benefits gained from waste minimization and recycling are huge. For example, before decision-making is considered for many projects, an early start investment analysis is performed in order to determine the feasibility of embarking on individual project [36]. Calculating the costs of reuse and recycling and other diversion activities and comparing them with the disposal costs, a few studies also discussed the direct and indirect and indirect impacts of an increased level of waste diversion on the number of jobs created and sales of secondary (recyclable) materials [35, 36, 37].

Liu and Wang [37] conducted a location-specific cost analysis of C&D waste management in Pearl River of China. This study used detailed formulas for calculating costs of three typical kinds (landfill, recycling and reuse) of disposal routes of C&D waste.

Liu and Wang study shows that between 2010 and 2013 the region cost for landfill of C&D waste has increased as compared to the costs of recycling and reusing C&D waste form site collection waste management. The study suggests that the government should make proper compensations to local contractors to reduce waste disposal costs and promote C&D waste management.

Another economic-based study carried out by Jain [38] focused on the problem of construction waste and management awareness, techniques and practices in the Indian construction industry. This study evaluates the economic feasibility of construction waste management of projects in India. The paper used the cost-benefit analysis approach and found that costs are the key man determinants for decisions and choices for waste management technologies and practices. However, the study concludes that with proper site waste management, it is economically feasible to do significant cost savings from the whole process where total benefits of waste exceeds the total costs of reducing, reusing and recycling [38]. It is important to understand that optimization occurs typically with respect to financial implication such as costs and project risks. This led to the discovery of another important management tool found in literature - risk assessment, which is further discussed. Risk assessment (RA) tool is a holistic term covering different types of assessment. It is quite clear that risk assessment cut across many aspects, however, there is clear distinction between risk assessment of chemical substances and risk assessment of accidents. Risk of accident relate to unplanned incidents such as explosion and fire, which is contrasting to risk assessment of chemicals [39]. There is a growing interest in the environmental aspect of risk assessment [39].

Gao et al. [40] conducted environmental risk assessment of heavy metals in C&D waste from five sources (chemical, metallurgical and light industries, and residential and recycled aggregates). This study concludes that the risk assessment for specific chemical substances (Zn, Cu, Ni and Cr) found in C&D waste posed a very high risk while some substances such as Pb and Cd as a lower risk. Hu et al. [41] conducted a dynamic material flow analysis (MFA) for C&D waste in an urban housing system in Beijing. The effects on C&D waste flows of housing floor, per capital floor area, the concurrent consumption as well as wast stream of concrete were investigated. Authors considered and analysed three scenarios involving current trend, high GDP growth, and lifespan of housing system. The study concludes that the higher the GDP, the lower the 'per capital floor area' in future terms and that recycling is a better option. The study further implied that by prolonging the lifespan of dwellings, it is possible to postpone the arrival of the peak C&D waste. MFA is a very useful systematic tool commonly used in quantifying flows and stocks of materials or substances in a well-defined system [42]. Conversely, waste management systems are often closely linked to energy systems as significant amount of greenhouse gases are emitted through processing [27]. However, there are limitations in some cases on local level energy systems. A few studies have discussed energy systems modelling to integrated municipal solid waste management [43, 44].

Kostantinidis et al. [43] developed a generic energy system tools in the urban environment to examine the impact of urban form and layout on inhabitants behaviours, which determines the demands for various resources. This study used the energy system tool to study eco-town with a given layout and set of resources demands where these are compared with solid waste to landfill. Zhao et al [45] modelled and compared different demolition waste recycling and reuse centres in Chongqing based on system dynamics approach. This paper analysed the cost benefit of various consolidated waste and concluded that three key factors impact the cost benefit as further suggestions and recommendations to enrich waste management optimization were presented [45]. System dynamics is an approach to understanding the nonlinear behaviour of complex systems over time using stocks and flows; internal feedback loops ad time delays [45, 46]. System dynamics is considered to be mathematical modeling technique for framing, understanding and discussing complex issues and problems [45].Yuan et al. [46] developed a system dynamics modelling of demolition waste processing in Shenzhen. This paper analysed the sensitivity of each parameter in the waste system flow and concluded the significant trends with the cost-benefit curve of the disposal facilities. This study further recommends measures to enhance the key contributing factors. The different approaches can be described as systems analysis tools. Thus, the expectations of system dynamics tools often are quiet high, where this is sometimes unachievable. Arguably, choice of method can be considered wrong or right depending on the situation to be assessed. Also, data with system analysis tools often gives methodological uncertainties, which are significantly large and often leads to unclear conclusions and justifications. The choice of the appropriate decision support tool in different situations is largely considered by two key perspectives: 1) entity under study and 2) significant impact of concern [47, 49].

Table IV below shows the arrangement of different waste management tools discussed above with regards to these two key perspectives. The discussion presented in this paper focused on both environmental and economic impact categories, however, the types of entities discussed in literature are: projects, firms/organisation, programme, plan, policy, product/service, and chemical substance. Table IV can be used as guidelines in considering the appropriate decision support model for C&D waste management. For example, if there is a need to compare and contrast the environmental impacts of various policy options (i.e. recycling, incineration, landfill, reuse, and collection), a Life Cycle Assessment (LCA) and Multi-Criteria Decision Analysis (MCDA) would appropriate tools for such measure. Other tools such as EIA and SEA are reliable practical tools used for predicting environmental consequences (positive or negative) of a plan, policy, program or project prior to the decision to proceed with the proposed action. Thus, these two models often incorporate LCA and RA respectively in their evaluation process. For basic economic impact measurement for C&D waste management CBA tool would be an appropriate tool to be considered for such assessment. However, other economic tools are applied in relation to different situations and assessments. Despite the opportunities for various waste management tools, there are key limitations found in literature.

TABLE IIIV
MANAGEMENT TOOLS ARE SHOWN IN RELATION TO THEIR OPPORTUNITIES AND IMPACTS FACTOR. BOTH PRACTICAL & SYSTEMATIC TOOLS ARE DIFFRENTIATED BY BOLD & ITALICS TEXT. MODIFIED FROM FINNVEDEN AND MOBERG [45]

| **Type of Entity** | **Impacts** | | **Mode/Approach** | |
|---|---|---|---|---|
| | **Environmental** | **Economic** | **Optimization** | **Universal decision support approach** |
| Projects (construction and demolition works, manufacturing, civil works etc.) | **EIA** | *CBA* and other economic measure | | *MCDA, DSS* |
| Organisation (firms, small business, Large-scale company, small-medium scale business etc.) | Environmental audits | Economic model/audits | *MCDA, AHP,* systems models of waste management | *MCDA, DSS,* System engineering |
| Chemical substance | *MFA, RA* | n/a | n/a | |
| Products/service | *LCA* | *LCC* | | *LCA* with *MCDA* |
| Policy, programme and Plan | **SEA** | Impact Assessment | *RA* | |

## III. LIMITATIONS AND IMPLICATION TO PRACTICE

### *A. Possibilities to Predict the Future*

Most decision support tools designed for waste management are often used to inform decision makers about policy options available for waste management optimization. Thus, these tools may inform decision makers about the prediction for possible or likelihood of direct impact of each decision made of various policy options. Decisions whether or not to recycle, reuse or disposal waste to landfill are weighted and ranked by decision makers in relation to impact measures. Waste management investments are known to be lasting operations to address both economic and environmental issues and concerns. For example, recycling and composting operations are considered to be viable as compared to landfilling, however, such investments depends on future development of advance technologies – the more technology involves the greater the energy use. This key limitation is considered in terms of energy use and the release of greenhouse gases, as it is almost impossible to predict associated costs as investment expands. The use of MCDA tool in few studies [12, 17, 28] has shown the possibility of uncertainty in measurement. The limitations found in MCDA techniques are that personal judgment and experience may be required to minimize uncertainty. Dealing with uncertainties within the MCDA framework required careful assessment and consideration in practice. As noted in Borhne [48], Ulukan and Kop [13], and Milani et al. [30] uncertainty is an important part when building a MCDA model. The common uncertainties in MCDA model are variations and lack of knowledge [30].

### *B. Composition of Various C&D Waste Materials*

The knowledge of handling different types of C&D wastes composition and chemical substances, which maybe hazardous in nature pose significant limitations. Societal acceptance on how solid wastes are used, particularly chemical substances maybe limited and may create major challenge for assessment. This simply means that there might be possibility of lack of knowledge on content, characteristics and properties when construction and/or demolition materials end up as waste in combined state. There are tendencies that chemical substances are often diverted to landfill since the actual amount and content cannot be determined from its original source and this leads to the uncertainty that we cannot justify or make reliable assessments for the actual greenhouse gases released through the processes.

### *C. Scientific Perception of Different Processes*

Although understanding is widely believed to be a (if not the) central aim of science, the philosophy of science has had surprisingly little to say about why certain things happen. With the knowledge of the content of waste stream, there are still limitations in practice around world. With the growing concern about global warming and basic environmental concerns, estimating actual greenhouse emission has become relatively impossible for future predictions. The use of management tool such as LCA model has its downside in terms of uncertainties in waste material flow system. In light of this, one can conclude the uncertainty in LCA model is scenario based – as different cases pose its challenges. This simply relate to different choices made e.g. waste material allocation, cut-off, etc. Thus, this can cause significant variation of results, which can be quantified through sensitivity analysis. However, model uncertainty creates key challenges for LCA model and this is as a result of insufficient knowledge of the mechanism of the studied waste system flow, becoming relatively impossible to quantify. Processing technologies often changes overtime as it directly or indirectly affect the output of the system within the assessment framework. This further prevents consolidated empirical data to be achieved when being investigated.

### *D. Criteria and Weighting of Impact Categories*

Different management tools discussed above tend to measure various impacts by weightings against individual criteria set. For example, the MCDA tool sets goal and objectives, followed by criteria and further decomposes this into various alternatives/options, which are weighted against each other. Morrissey and Browne [7] argue that the allocation of weights are subjective and often affect end results. Finally, the authors pointed out that the MCDA technique limits to ease of approach as some aspect are very cumbersome and unwieldy. Also, the economic model and related environment assessment focused on cost benefit analysis and the economic value (weight) of major impacts on the environment [5, 21]. It is imperative that individual weighting technique developed can be disparagingly discussed and evaluated [5]. The limitations found in these methods in relation to impact measure are that the actual values cannot be determined as the outcome of most weightings are often criticised.

### *E. Possibilities of Having a Site Location-Specific Measure*

There are a number of local and global impacts (i.e. noise and vibration disturbance, global warming, greenhouse gas, $CO_2$ emissions etc.) to C&D waste management. However, there are limitations to waste management techniques, approaches and models performed by various locations, regions and countries. For example, rate of production recycled and reused materials can varies from regions, locality/districts, construction sites etc. Waste systems are managed and investigated within a time frame by the help of LCA model where environmental impact measurement is incorporated. The technology used in such process may vary in other area and there is a need for many waste management facilities to be more location-specific and have broad system approach to fit into all types of waste management endeavours. This lead to the uncertainty in using diverse models for waste management in practice, and also it affects the definite conclusions in considering appropriate model for waste management optimization. However, Table IV provides guidelines for appropriate decision support models for various entities and scenarios of waste management.

## IV. CONCLUSIONS

Considering appropriate decision support models for C&D waste management optimization can be very difficult in some cases. However, with careful selection criteria in place as discussed in the paper there will be tendency to apply the right model for the right C&D waste management scenario. This paper reviewed available management models and provided some key insights into selecting appropriate decision support model as well as it has discussed key opportunities and limitations to waste management decision support models. The study found that a number of studies have discussed models for decision making in solid waste management [8, 9, 12, 13, 18, 22]. However, in these studies, only a few have provided key guidelines in selecting appropriate models for decision making in solid waste management [22, 31, 32]. It is important to understand that waste management on it own is colossal and complex in nature to investigate.

Common models such as LCA, LCC, MFA, CBA, System Analysis/Dynamics, and MCDA have been found in literature with individual opportunities and limitations. LCA model among other models provides a more comprehensive analysis and assessment of environmental impact of a products or processes. LCA model helps in reducing the impacts of processing C&D waste system at designated facilities. MCDA tool on the other hand provides a clear and transparent methodology for making decisions and also offers a formal way for combining information from disparate sources. Both LCA and MCDA system tools are often used for trade-offs. However, the limitations discussed in this paper for these two models, along with valuable insights into careful consideration via guidelines provided will further enhance decision making during modelling tool selection process. Other practical tools such as EIA and SEA have been found useful in decision-making in predicting environmental consequences (positive or negative) of a plan, policy, program or project prior to the decision to proceed with the proposed action. The paper, however, suggests that the choice of individual models should be situational as demonstrated in table IV and that decision makers should play a key role in the selection process in order to appraise solid waste management at its full potential. Thus, basic assumptions in the use of some waste management models can be criticised and it may be difficult to use these as industry-wide systems for managing solid waste for all construction/demolition projects.

## ACKNOWLEDGMENT

The authors would like to acknowledge the suggestions of the editor and two anonymous academic reviewers.

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## Appendix 14

## Academic Paper 4

Oyenuga, A. A. and Bhamidimarri, R. (2015), “Sustainable Approach to Managing Construction and Demolition Waste: An Opportunity or a New Challenge”, Paper submitted to SSRG International Journal of Innovative Research in Science Engineering and Technology (IJIRSET) November 2015

ISSN(Online): 2319-8753
ISSN (Print):2347-6710

International Journal of Innovative Research in Science, Engineering and Technology

*(An ISO 3297: 2007 Certified Organization)*

**Vol. 4, Issue11, November 2015**

# Sustainable Approach to Managing Construction and Demolition Waste: An Opportunity or a New Challenge?

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**ABSTRACT**: The handling of wastes remain a perpetual problem, all construction and demolition works and activities are confronted to this issue. Many investors, clients, construction and demolition professionals consider C&D waste management one of the most essential green construction practices in support to energy efficiency. In fact, there is a growing interest in sustainable waste management as potential stakeholders are pursuing innovative and integrated waste management and environmental strategies. Sadly, most traditional approach to reducing C&D waste is considered to be unsustainable as it lacks flexibility and long-term reliability. Thus, the move to a more sustainable society requires sophisticated approach to manage C&D waste, which incorporate feedback loops and focus more on processes, embodies adaptability and diverts waste from landfill disposal. This paper review current C&D waste management practices and propose a conceptual framework for optimising C&D waste management. The study adopts a Life-cycle (LCA) model based on C&D waste sustainability measure (LCASM) to justify the need for a green approach to C&D waste management. The central focus of the LCA model is to minimise C&D waste disposal and to enhance the application of 3Rs (reduce, reuse, recycle) concept. The study sought to determine whether this sustainable approach to C&D waste management is an opportunity or a new challenge. Recommendations are provided on how to enrich C&D waste management optimisation processes.

**KEYWORDS**: Construction and demolition (C&D) waste, green initiative, sustainability, 3R's principle, Life-cycle Analysis (LCA), Factor Analysis (FA), Analytic Hierarchy Process, waste management.

## I. INTRODUCTION

The construction industry have been challenged by the unacceptable levels of waste generation over the years [1] Today, the construction industry has become increasingly aware of the importance of both economic and environmental impacts associated with waste generated during both the construction of new buildings and the demolition of old structures [2]. This is as a result of the significant amount of construction and demolition (C&D) waste generated which as huge impact in contributing to environmental damage both nationally and internationally [3, 4]. It is important to understand the C&D waste system which covers a broad range of building materials is often categorised as: waste arising from total or partial demolition of buildings and/or civil infrastructure, waste arising from the construction of buildings and/or building civil infrastructure, social, rocks and vegetation arising from site clearing, earth moving, civil works and/or excavations for foundations and materials arising from road construction and maintenance works [5]. With the increase in C&D waste generation through construction activities, the construction industry has been challenged with issues relating to economic and environmental impacts resulting from lack of waste minimisation techniques.

The economic and environmental benefits expected from C&D waste minimization are relatively essential [6, 7] as it provides key benefits to both the environment and the construction sector. Sadly, one of the key challenges to waste minimization is inability to apply a more sustainable approach and devise proper management strategy in order to reduce and/or prevent construction waste stream.Sustainable construction has received much attentionthroughout the world over the last few years. The concept of sustainable construction is relatively new to the construction industry and

DOI:10.15680/IJIRSET.2015.0411007

it often depicts the following attributes: a social progress, which recognizes the needs of everyone, effective protection of the environment, prudent use of natural resources, and maintenance of high and stable levels of economic and growth and employment [8]. According to BREEAM's definition [9] sustainable design and construction is concerned with implementing sustainable development at the scale of individual sites and buildings. It takes account of the resources used in construction, and of the environmental, social and economic impacts of the construction process itself and of how buildings are designed and used. The term sustainability may seem like a new name or an old concept with direct links to energy conservation, natural resource preservation, or waste reduction at its full potential. Today's concept of sustainability embraces all these ideas and maybe more, as the society at large pursue integrated approaches to green initiative [10]. The idea of sustainable development seems to be the best practice solution to managing C&D waste within the construction sector in order to enhance the durability and use of recycled materials as well as eliminating the development of building waste throughout the construction life cycle [1]. The significant improvement in construction site practices worldwide have led to C&D waste reduction through the reuse/recycle operations.

**Table 1**: C&D waste category and its sustainability potential: opportunities with reuse/recycle

| C&D waste composition | Reuse/recycle Operations/Opportunities | Landfilling Potential | Composting/incineration | Market opportunity | Job creation |
|---|---|---|---|---|---|
| Paper/Cardboard | Composting, fire kindling, new product development (paper production) | No | Yes | Yes | Yes |
| Glass | Recyclable to new product (new glass development) | No | No | No | Yes |
| Metal | Reusable and recyclable to metal components | No | No | Yes | Yes |
| Hard-core | Reuse of rock, silt, rubbles for potential local market | Yes | No | Yes | Yes |
| Plastic | Plastic is recyclable to new product development | No | Yes | No | Yes |
| Building Materials | Reuse of salvage material for potential market | No | No | Yes | Yes |
| Plasterboard | Recycled gypsum board to new product, crushed wall as clay and silt mixture subject to compost | No | No | No | Yes |
| Wood | Recycled wood to create veneer board/paper pulp and reused wood product for potential market | Yes | Yes | Yes | Yes |
| Concrete | Recycled aggregate for civil works, road construction and modular panels | Yes | No | No | Yes |
| Soil, Sand & Gravel | Reuse soil/sand/gravel via excavation for potential market | Yes | No | Yes | Yes |

This paper review the different applications used in current C&D waste management practices and further propose a conceptual framework for optimising C&D waste management. The study adopts a Life-cycle model based on C&D waste sustainability measure (LCASM) to justify the need for a green approach to C&D waste management. The proposed model focused on the minimisation of C&D waste disposal and the enhancement of the application of 3Rs (reduce, reuse, recycle) concept. The study sought to determine whether this sustainable approach to C&D waste management is an opportunity or a new challenge. Finally, the paper concludes with a recommendation to enrich C&D waste management optimisation and a summary of key research findings.

## II. CHALLENGES AND OPPORTUNITIES FOR C&D WASTE MANAGEMENT

### *C&D waste generation*

Construction and demolition (C&D) materials are generated when new structures are built and when existing structures are renovated or demolished.Structures include all residential and non-residential buildings, as well as public works projects, such as road, bridges and dams [10]. Materials resulting from construction and demolition of buildings and infrastructure constitute a significant amount (10-15%) of the total municipal solid waste stream [4].The UK generated 200 million tonnes of total waste in 2012. Half of this (50%) was generated by Construction, demolition, renovation and refurbishment works. Commercial and industrial activities generated almost a quarter (24%), with households responsible for a further 14%[11]. For the most part, construction wastes are largely slothful. The key challenge is that construction waste is bulky, solid to compress and often occupies space in overstrained and confined municipal landfill [8]. Reducing C&D waste is a priority for the European Union and the UK Government and there are many new regulations, measures and targets to reduce waste within the construction industry [11].Figure 1 below shows both construction and demolition waste composition at various stages in the UK in 2014. The key challenges with the generation of large amount of C&D waste on many construction sites is to apply operations such as reuse and recycle techniques which final leads provide sustainability in construction and demolition works and often led to the development of new products.

(1) (2)

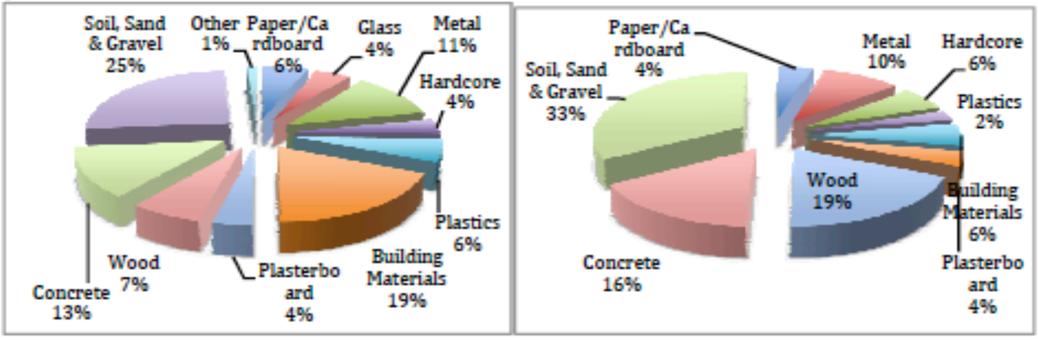

**Figure 1**: C&D Waste streams at various stages of construction and demolition: (1) Construction Waste Composition, (2) Demolition Waste Composition (Source ONS, output in the construction/demolition sector, 2014).

### *Opportunities with C&D waste*

Good practice in construction and demolition materials recovery facilities have driven the increase awareness of sustainability with the construction industry. Recovering of non-inert C&D materials requires strategic approach with measurable objectives. There a lot of cost saving by reducing the amount of C&D waste developed. Source reduction, however decreases disposal costs, lowers labour costs because less materials must be handled and cut and reduces spending for materials because less is wasted [12]. When site space allows, on-site source separation of C&D materials can yield reduced or eveneliminated tipping fees. In the case of steel and other metals, revenue can be received fromsalvage value.Time-based removal of C&D materials can be an effective method of segregating materials onsmaller projects [13]. C&D waste amount to about 17% of the total waste in the United Kingdom being reused and recycled as opportunities continue to grow over time [14].

*Sustainable Approach – A pursuit for 'green' initiative*

There had been a competitive race for sustainable development across the world, primarily in the construction industry. Green initiative in construction was driving by the need for sustainable development. Since 2012, there have been significant efforts to fulfil the sustainable approach to C&D waste by investing on *"Halving C&D waste to Landfill"*as implemented by the UK Sustainable Construction Strategy [15]. This initiative sets a national target to *"Zero C&D waste"* to landfill by 2020 as UK Government continue to embark on a long term ambition to end the disposal of C&D waste in landfill as far as practicable. In order to meet the target set for 2020 national policy on waste management has been strengthened by preparing for a more sustainable approach to reuse, recycle and other material recovery practices [15]. Following the pursuit for green initiative, a number of fiscal and regulatory measures such as landfill taxes, aggregate levy, Site Waste Management Plan, BREEAM standard (offering credit for diversion of C&D from landfill 75% by weight and 65% by volume) are already driving resource efficiency [16].

*Green Initiative vs. Traditional Waste Management*

There are clear distinctions for values derived from green initiative (sustainable C&D waste management) and the system used in landfill disposal site (traditional waste management). Green initiative to managing C&D waste include all forms of reducing, reusing, recycling as well as waste-to-energy projects. This idea seemed to conserve energy, preserve natural resources and/or maximise waste reduction at its full potential. It is considered that most traditional approach to reducing C&D waste is considered to be unsustainable as it lacks flexibility and long-term reliability. By reducing the amount of waste being diverted to landfill the value of waste can be justified and re-evaluated in terms oflong-term vision. There are also great opportunities found with reducing C&D waste such as best practices, recognitions and award, high revenues generation and job creation. However, there is a need for green initiatives to be re-evaluated in terms of new technologies and the provision of essential knowledge of logistics, operations and the regulatory context.

*Design out Waste*

The ultimate goal of sustainable approach to C&D waste is to strategically reduce the amount produced. The site waste management practices across the world have been able to fulfil this vision. Arguably however, the best opportunities for enhancing materials resource efficiently in construction projects occur during the design stage [17]. Implementing these possible opportunities can further provide huge reductions in cost, waste and carbon emissions. Designers often use five key principles (design for reuse and recovery, design for off-site construction, design for materials optimisation, design for waste efficient procurement and finally design fro deconstruction and flexibility) these five principles are mostly guided by an extensive consultation, research and work carried regulatory bodies. It is quiet important to understand the design for reuse of material components and/or entire building has substantial potential to reduce the environmental weights from construction. With reuse, the effective life of materials is extended and thus annualised weights are spread over the years. Reuse, on the other hand in the waste hierarchy is generally preferable to recycling, where additional processes are involved [18]. The advantage of designing for off-site construction are well discussed in modern times as this process has potential in reducing C&D waste.

*Implementing 3R's Principle*

C&D waste management is required to be carried out after passing different stages. Figure 2 below indicated the various stages required for waste management based on hierarchical model as suggested by Peng et al. [18]. These authors recommends that waste management should be executed by reducing, reusing and recycling of C&D waste. However, certain events such as avoidance and minimisation, which further depicts the reduction, process alongside the recycling operations, which are considered to be desirable. Waste management concept is guided by level of hierarchy known as the 3R's principle explained by El-Haggar in 2007 [19]. This model produces an integrated approach in which options of waste management can be considered and thus serves as a systematic tool for those who generate and manage waste [20].El-Haggar argued that when waste is being managed effectively it could generate various benefits through the whole life cycle of the waste from its generation to its end disposal [20]. Significantly, it is believed that proper construction waste management will provide both economic and environmental benefits.

**Figure 2**: Waste management hierarchy model

*Environmental Impact of 3Rs principle – Energy recovery*

The application for 3Rs (reduce, reuse and recycle) principle is considered to have both economic and environmental benefits. However, the underlying question is *"how to do energy recovery by means of 3R principle?"*. A new model was developed in early 2011 for recovering energy based on 3Rs principle [21]. It is clear that the 3R principle of waste management hierarchy was introduced to fulfil its aim by providing the most preferred option to effectively and sustainably managed waste. All construction and demolition processes such as designing, constructing often leads to waste development and often managed by 3Rs principle, which is important to the 'green initiative' as provided for sustainable construction [2]. Energy is effectively recovered to this process with the intension to be beneficial to the entire environment on a long term.

*Life Cycle Assessment – A sustainable approach to C&D waste*

On a broader perspective, environment impact and concern are considered for all waste products either solid or non-solid waste and these forms a resource standpoint where waste hierarchy leads to the most resource-efficient and environmentally sound choice and positive outcomes. Lifecycle assessment support decision-making in the field of waste management and also helps to determine environmental viability. The LCA is a popular tool used to investigate the potential environment impact, throughout a product's life. The LCA methodology was first developed by ISO standard by considering four phases, namely, goal and scope definition, inventory analysis, (input/output), impact categories and interpretations. By analyzing the positive and negative environmental effects of all kids of projects or products, LCA pose as a reliable tool considered for several areas to analyze and to evaluate different alternatives. Huang et al. [23] adopt LCA to evaluate environmental impacts of using recycled materials in asphalt pavements. The authors evaluated relevant LCA model can be used a decision support tool for sustainable construction in the road industry. Other relevant LCA studies [24, 25, 26] on construction waste management as the study of Cherubini et al. [24] discouraged the diversion of construction waste to landfill in relation to environmental impacts. The integration of LCA in the construction sector as two perspectives (1) building material and (2) construction processes. These two elements further relate to C&D waste management phases: pre-construction phase, construction and renovation as well as demolition phase as indicated in figure 3 below.

ISSN(Online): 2319-8753
ISSN (Print):2347-6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue11, November 2015

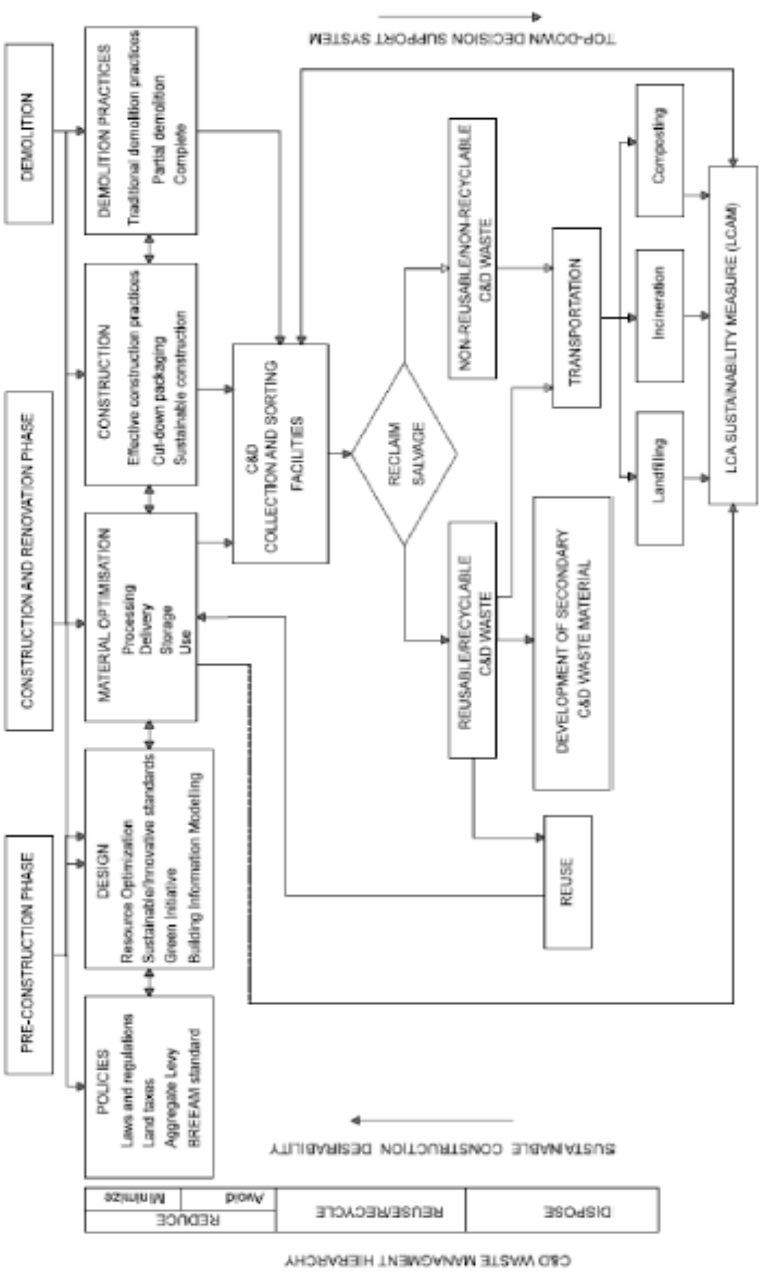

Figure 3: Conceptual framework for C&D waste management flow system using LCA mapping

DOI:10.15680/IJIRSET.2015.0411007

Information provided in figure 3 shows that each stage of the construction project life cycle consider C&D waste management hierarchy using the 3Rs (reduce, reuse and recycle) principle.The LCA inventory covers the input and output and that impact outcomes are derived from the inventory data processed. The life cycle map is developed to explain the waste material flow from the system start to finish. Sustainable approach to the waste flow system often supports reuse and recycle and reduction of disposal to landfill. Energy saving and natural resources are often conserved by reuse and recycling operations and the fact that there is a significant reduction of waste being diverted to landfill, the environmental concern can be easily addressed through this initiative.

*Pre-construction phase – Planning and Design*

The early stage of construction often cover the planning and design phases which are considered very thorough through a construction project life cycle. Designers such as architects, civil engineers, and CAD technicians are expected to design building following guidance from the WRAP "design out waste" [17]. Thorough consideration is giving to standard sizes, densities, positioning and height to improve the process of waste minimization and predominantly to achieve significant cost savings in construction. Recyclable/secondary building materials are required to be incorporated in design at the pre-construction. Architects have a major role to play in providing the right specifications when designing out waste. This approach presents a proactive target options to reduce waste, recognizing that some key solutions on a project are most likely to achieve waste minimization, along with cost savings, carbon reduction and other related benefits. Solid waste management practices have identified the reduction, recycling, and reuse of wastes as essential for sustainable management of resources.Addressing problems of C&D waste and best practices for most designers are assumed to be the avoidance of waste during design phase as it helps many to identify early problems with design concepts [26]. At the preconstruction stage of many construction project, local and national regulations and laws applies as well as incentives to encourage professionals to embark on the use of 3Rs concept. The introduction of the Site Waste Management Plan have helped many professionals to significant cut down the amount of waste through construction and demolition works. Most importantly, the introduction of the BREEAM standard, which offers credit for diversion of C&D from landfill 75% by weight and 65% by volume, continue to improve resource efficiency [16]. To move towards a more sustainable approach to waste management for construction and demolition projects the pre-construction phase consider the use of Building Information Modelling (BIM).

*Building Information Modelling (BIM) – Application on Waste Reduction*

Building Information Modeling (BIM) is changing how buildings, infrastructure, and utilities are planned, designed, built, and managed. This unique tool is a process involving the generation and management of digital representations of physical and functional characteristics of places. Quantitative waste prediction is crucial for waste management. It can enable contractors to pinpoint critical waste generation processes and to plan waste control strategies. In addition, waste estimation could also facilitate some government waste management policies on local taxes, recycling rate, and aggregate levy [27]. BIM is considered a type of estimating tool that can accurately and conveniently estimate the amount of waste from construction, renovation, and demolition projects. The concept of green building and sustainable design is becoming a main factor for change in construction projects within the built environment owning to its effectiveness on reducing energy consumption and material usage. BIM plays an important role with regards to reducing waste during design and pre-construction phase. BIM filters into the major generation source of waste and eliminates the non-value adding activities that are nor consistent or necessary [28]. The premise behind BIM is coordination of among all stakeholders in different phases over the lifecycle of a facility that will help to insert, extract, update or modify information. BIM provides a design team with a tool to evaluate the impact of the design decisions on the overall construction process with the assistance of virtual prototyping on the other hand; it is widely acknowledge that associating BIM with development and use of 3D parametric, 4D time dimension and 5D which is the quantities and costs of material. BIM solutions for C&D waste reduction include conflict, interference and collision detection, construction sequencing and construction planning, reducing rework, synchronizing design and site layout and detecting errors and omission in design [28].

### III. LCA SUSTAINABILITY MEASURE (LCAM)

Measuring sustainability within the C&D waste management system is not an easy task. To quantify the amount of waste system under study requires certain parameters used by decision makers. Both qualitative and quantitative measure is considered for the LCA measurement. To measure the amount of C&D waste within the system flow, information is collected and measure against based criteria and parameters. LCASM parameters are shown in figure 3 and are further divided into two elements (1) the criteria set include economic, environmental and social impact for C&D waste processing, storage, transportation and disposal (2) weightings of the LCAM based on decision makers input. Figure 4 shows the hierarchical process of estimating C&D waste management system flow via LCA.

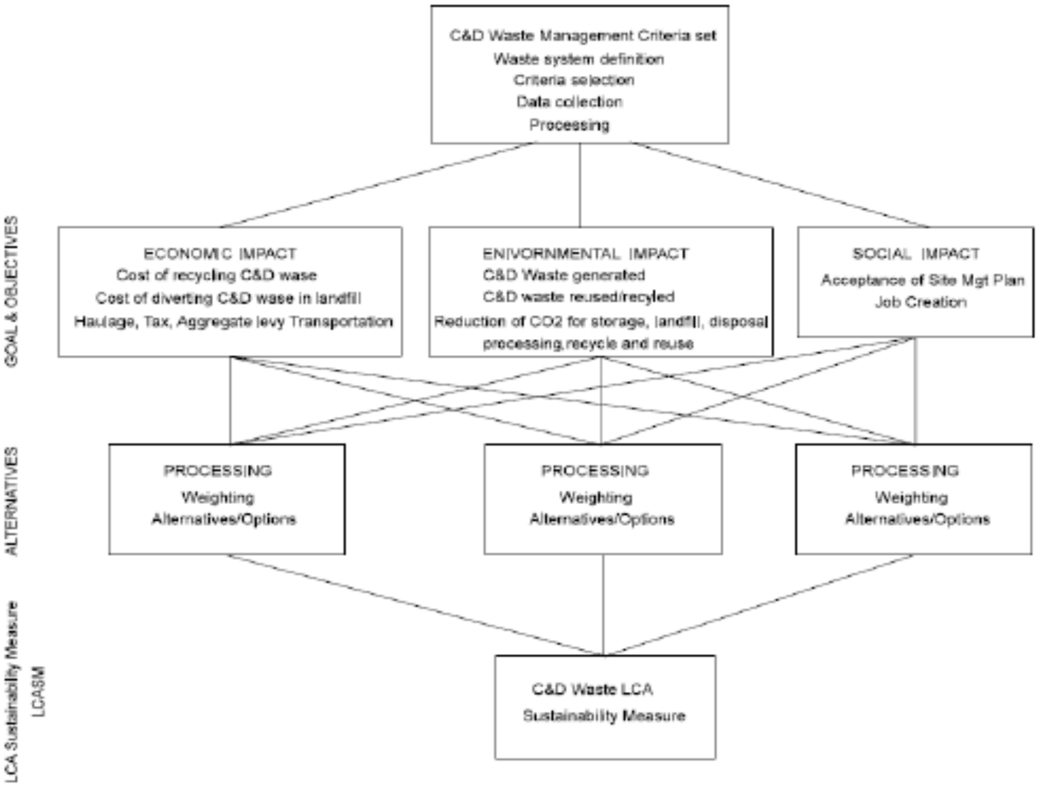

**Figure 4**: Hierarchical process for estimating C&D waste management system flow

The first step involved in the LCASM is the selection of suitable parameters linked with the three criteria set (economic, environmental and social impacts). The evaluation of C&D waste management with its sustainable potential, basic performance measure is considered in terms of the environment measure in terms of reduction of carbon emissions through transportation, storage, processing, landfilling, composting, recycling and reuse operations. Both economic and social impact relate to cost-saving capability of recycling, landfilling, recycling gate fees, haulage, aggregate levy and local taxes, social acceptance, job creation are considered. The social impact measure under the LCA inventory category helps to determine the extent of social acceptance of Site Waste Management Plan, recycling operations, and job creation through various reuse/recycling operations. The goal and objective set for measuring the economic, environmental and social impact of C&D waste forms the three pillars of sustainability. To successfully justify the measure for LCASM, the weighting system is normalized and aggregated. Choosing alternatives or options to C&D waste management requires decision maker's preferences. The parameters considered for LCASM is introduced to understand how (economic, environmental and social) impact affects the successful optimisation of C&D waste management. The weighting systems consider different alternatives for managing C&D waste system. However impact categories for LCA such as economic, environmental and social impacts are directly linked to sustainable measure of successful C&D waste management techniques. Detailed discussion of expert information incorporating both quantitative and qualitative criteria with numerous levels of criteria can be found with popular weighting models such as Analytic Hierarchy Process (AHP), Factor Analysis (FA), and Equal Weighting (EW) respectively.

*Implication to Current Practice*

The current state of managing C&D waste still pose some challenges as more techniques are introduced in recent times. The current C&D waste practices. There are many other impacts categories (i.e. noise and vibration disturbance, global warming, greenhouse gas, $CO_2$ emissions etc.) for C&D waste management. Arguably, there are limitations to waste management techniques performed locally and internationally.For example, rate of developing recyclable and reusable waste materials often varies from regions, districts, and construction sites.With the growing concern about global warming and basic environmental concerns, estimating actual greenhouse emission has become relatively impossible for future predictions. The use of LCA model has its downside in terms of uncertainties in waste material flow system [29]. C&D waste systems are effectively managed and investigated within a set time frame and schedule by the help of LCA with great attention of justifying the environmental impact. Thus, the technology used in such process often varies in a number of districts as waste management facilities to becoming more location-specific. This results to the challenges facing sustainable approach to managing waste as the broader the extent of measurement the more the uncertainty in using varieties of techniques for waste management in current practice [24]. The three pillars (i.e. environment, economic and social) of sustainability have become a popular criteria t be consider in terms of LCA measure. However, C&D waste management have pose some kind of opportunities to explore these three measure as the opportunities found in recycling and reusing C&D waste are far more seen visible in terms of job creation, cost savings and conserving natural resources [25].

## IV. RECOMMENDATIONS

The C&D waste management practices have successful account for carbon emissions, social impact such as acceptance and employment opportunities as well as the cost-savings initiatives. Thus, these impact categories still face challenges today as sustainable construction seemed to attract the entire society. To enrich the C&D waste management optimisation processes there is a need to rethink the techniques considered for recycling and reusing C&D waste management and access the opportunities within these processes. To maximise the full reduction of C&D waste, the BIM tool have proven its worth in waste reduction as the tool can accurately and conveniently estimate the amount of waste from construction, renovation, and demolition projects. Using BIM tool, the construction industry have been able to demonstrate on-time project delivery and zero waste initiative in the last few years. Thus, the 3R's principle remains an ultimate fundamental concept that assist in achieving sustainable construction desirability.The study, however, recommends that to incorporate sustainable approach to C&D waste, it is essential to consider the right model to access sensitive impact categories not only economic, environment and social but also institutional and political challenges to C&D waste management. LCA model continue to become a sustainable tool that provides a more comprehensive analysis and assessment of environmental impact of a products or processes. Significantly, LCA often helps in reducing the impacts of processing C&D waste system at designated facilities. For the weighting systems where goal/objectives are measure against individual criterion and alternatives to C&D waste, the Analytic Hierarchy Process (AHP) model continue to outperform other similar models as its focus more on providing expert information incorporating both quantitative and qualitative criteria with numerous levels of criteria, Thus, the opportunities found within this model are far more than the challenges seen within.

## V. CONCLUSION

There is plenty of interesting way to demonstrate the benefits derived from managing C&D waste within the construction industry. One of these ways is by meeting the sustainable construction needs and providing value for many construction projects. The use of innovative tools such as LCA, AHP, FA etc. gave a better approach to weighing various options for effective management of C&D waste. However, sustainable approach to C&D waste management cannot be performance without its challenges. The opportunities within this process outnumber that found in challenges within. Job creation through various stages of C&D waste processing, disposal and transporting have given the social value of effective management of C&D waste. This paper reviewed available and current waste management practices and provide implication to practices. The paper further proposed conceptual framework for C&D waste management flow system using LCA mapping. This framework considers the fundamental principle of 3Rs (reduce, reuse and recycle) and exploded this principle into an integrated LCA platform for C&D waste management with the consideration for four key project phases (i.e. pre-construction, design and construction, renovation and demolition). The proposed framework suggest that there are significant reduction of waste material at the design stage with reference to local laws and regulation, taxes, aggregate levy, BREEAM standard and the use of BIM tool. Sustainable approach to C&D waste incorporates these important factors and further provides a roadmap to how impact categories can be justified. Finally, the development of the LCA sustainable measure (LCASM) in the conceptual framework is intended to help decision makers to make inform decisions in relation to selection of various alternatives to managing C&D waste.

## ACKNOWLEDGMENTS

The authors would like to acknowledge the suggestions of the editor and two anonymous academic reviewers.

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## Appendix 15 - Certificates, Training and Awards

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SMARTWASTE

# Certificate of Training

Abioye Oyenuga

has attended and completed

smartERTraining

This event qualifies for 2.5 hours continuing Professional Development

Dated 6 Septembery 2011

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# CERTIFICATE OF ATTENDANCE

THIS IS TO CERTIFY THAT

**ABIOYE OYENUGA**

ATTENDED A COURSE OF
INSTRUCTION

**Career Development**

ON 14 NOVEMBER 2011

PROFESSOR PETER DOYLE
RESEARCH SKILLS COORDINATOR
LONDON SOUTH BANK UNIVERSITY

LONDON SOUTH BANK
UNIVERSITY

Postgraduate Certificate in Research Skills

Postgraduate Training Session

# CERTIFICATE OF ATTENDANCE

THIS IS TO CERTIFY THAT

**Abioye OYENUGA**

ATTENDED A COURSE OF
INSTRUCTION

**Academic Publication**

ON 10 NOVEMBER 2011

Professor Peter Doyle
Research Skills Coordinator
London south Bank University

Widener University

The Journal of Solid Waste Technology and Management

## *The 29th International Conference on Solid Waste Technology and Management*

*Philadelphia, PA USA*
*March 30 – April 2, 2014*

***Abioye Oyenuga***

*has presented the paper*

***Challenges in Managing Construction and Demolition Waste***

*at the above named Conference*

*Ronald L. Mersky, Conference Chair*

Widener University

The Journal of Solid Waste Technology and Management

# The 29th International Conference on Solid Waste Technology and Management

*Philadelphia, PA USA*
*March 30 – April 2, 2014*

## *Certificate of Attendance*

*issued to*

***Abioye Oyenuga***

*Ronald L. Mersky, Conference Chair*

# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY

**ISSN (Online) : 2319 – 8753** **ISSN (Print) : 2347 - 671**

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## PUBLICATION CERTIFICATE

This is to certify that

**ABIOYE A. OYENUGA**

**PhD. Student, School of the Built Environment and Architecture, London Southbank University, London, UK**

Published a research paper titled

**“Sustainable Approach to Managing Construction and Demolition Waste: An Opportunity or a New Challenge?”**

**in IJIRSET, Volume 4, Issue 11, November 2015**

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## Biographical Sketch

**Abioye Oyenuga** has studied the environmental and economic impacts of recycling and reuse of construction and demolition (C&D) waste for the past four years. Although born and raised in Lagos, Nigeria, he relocated to study in the United Kingdom in 2006, which was an inspirational and career-oriented mobility and educational strategy. He received both his Bachelor of Science (BSc.) and Master of Science (MSc.) degrees in Architectural Technology and Construction Project Management at the London South Bank University. After graduating in 2010, he worked for a construction and renovation firm (Dunamis Construction Ltd.) in Croydon, London as a CAD Technician/Project Assistant.

Following his passion for research and contributing to existing knowledge within the field of Construction and Demolition Waste Management, he returned to academia on a FSEBE scholarship to pursue a Doctor of philosophy degree at the London South Bank University. During his studies, he attended international solid waste conferences and published four papers between 2013 and 2015. Additionally, he has participated and nominated as an ambassador in a number of community-led young people initiatives in the United Kingdom such as Young Volunteers Drive, London Engineering Project (LEP), Science Technology Engineering Mathematics (STEM).