CARDIFF UNIVERSITY

Cardiff School of Engineering

Development of a Decision Making Tool for Waste Management: Case Study of a Local Authority in Wales

By

Alexander Lloyd Theodoros Davies

June 2016

A thesis submitted in partial fulfilment to Cardiff University of the requirements of the degree of Doctor of Philosophy.

DECLARATION

This work has not previously been accepted in substance for any degree and is not concurrently submitted in candidature for any degree.

Signed: ………………………….

Date: …………………………….

STATEMENT 1

This thesis is being submitted in partial fulfilment of the requirements for the degree of PhD

Signed: ………………………….

Date: …………………………….

STATEMENT 2

This thesis is the result of my own independent work/investigation, except where otherwise stated. Other sources are acknowledged by explicit references.

Signed: ………………………….

Date: …………………………….

STATEMENT 3

I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loan and for the title and summary to be made available to outside organisations.

Signed: ………………………….

Date: …………………………….

Abstract

The landscape for waste collection is ever changing. With constant adjustments in Government, increasing budget restrictions and changes in Legislation, Local Authorities have to adapt their collection methods to achieve the best recycling rates possible. The focus of their efforts is frequently on the cost; however there are many other drivers and barriers that they must pay attention to such as legislative compliance.

The aim of this study was to understand the interaction of these drivers and barriers. More specifically, the decision making process that they follow. A long term, consistent decision making process is required to maximise the amount of recyclate they can collect. A study of the decision making methodologies showed that the Analytic Hierarchy Process (AHP) was the easiest to understand and implement. By having an understandable methodology, the decision maker(s) have clarity and a solid reasoning for the choice they make. Also, by using a commonly understood software to create a programme meant a clear understanding and ownership of the decision made.

Scenarios were created to understand how the criteria interact and affect the choice of waste collection method. The interaction of criteria dependent on the size and type of Local Authorities was examined. Of all the criteria that could be taken in to consideration, Legislative Compliance, Net Running Costs and the Quality of the Recyclate collected were repeatedly the most important. The results gathered from the Case Study Authority were checked against these scenarios and it was found that they performed in the same manner that was expected from their classification by type and size of authority.

It was concluded that the decision making process, as a whole and in relation to waste management, was successfully understood. The novel development of the Analytic Hierarchy Process and inception of a decision making tool to clearly define the drivers and barriers that face a Local Authority were accomplished. The time sensitive nature of the process highlighted the difficulty assuring the right decision is made at any given time. Nevertheless, it was successfully applied to a Case Study Authority whose decision matched the ideals of the Welsh Government in suggesting a Kerbside Sort collection scheme.

Acknowledgements

None of this would have been possible without the belief and support of my supervisors. Now retired, Prof Tony Griffiths helped me to find funding first of all to make it all possible. From there, he was patient with me when I was going in to ‘consultant mode’, guided me where necessary and let me find my own way too. I could not have asked for a better supervisor. Also, Dr Steve Bentley helped me on the Local Authority front and opened doors that no one else could. I am indebted to both for the help, guidance and support they provided throughout the duration of the study.

Also, Nick Oakes of Ceredigion CC and Adrian Keenan, who has now moved on to my hometown of Solihull, have been invaluable to me. Their help to understand the aspects of waste collection that they face and to help with improvements meant that I was never stuck. So, my thanks go to them and their financial backing.

Over the years, my friends, family and loved ones have also been there for me. Firstly, my family. They have put up with my ups and downs, the times when I haven’t been in contact and been there no matter what, especially when I’ve needed a break.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AHP – Analytic Hierarchy Process

C&I – Commercial and Industrial

C&D – Construction and Demolition

CC – Commingled Collection

CI – Consistency Index

CO_2 – Carbon Dioxide

CR – Consistency Ratio

DEFRA – Department for the Environment, Food and Rural Affairs

DM – Decision Making

DSS – Decision Support System

DST – Decision Support Tool

EES – Economic, Environmental and Social

ELECTRE – Elimination and Choice Expressing Reality

EU – European Union

GHG – Greenhouse Gases

LA – Local Authority

LCA – Life Cycle Analysis

LCI – Life Cycle Inventory Analysis

LCIA – Life Cycle Impact Assessment

KSS – Kerbside Sort

MADM – Multi-Attribute Decision Making

MCDA – Multi-Criteria Decision Analysis

MODM – Multi-Objective Decision Making

MRF – Material Recycling Facility

MAUT – Multi Attribute Utility Theory

MSW – Municipal Solid Waste

OBC – One Bag Collection

OM – Outranking Methods

ORWARE – Organic Waste Research

PROMETHEE – Preference Ranking Organisation Method for Enrichment of Evaluations

RCV – Refuse Collection Vehicle

RDF – Refuse-Derived Fuel

RI – Random Index

rWFD – Revised Waste Framework Directive

SCOLDSS – Solid Waste Collection Decision Support System

SMART – Simple Multi-Attribute Rating Technique

SWIM – Solid Waste Integrated Management

SWM – Solid Waste Management

SWMG – Sustainable Waste Management Grant

TEEP – Technically, Environmentally and Economically Practicable

TZW – Toward Zero Waste

UK – United Kingdom

WAG – Welsh Assembly Government

WCA – Waste Collection Authority

WDA – Waste Disposal Authority

WFD – Waste Framework Directive

WG – Welsh Government

WM – Waste Management

WMP – Waste Management Plans

WPM – Weighted Product Method

WRAP – Waste Resources Action Plan

WRATE – Waste and Resources Assessment Tool for the Environment

WSM – Weighted Sum Method

Nomenclature

General

A_m – Alternatives

C_n – Criteria

w_n – Weighting of Criteria

x_n – Weighting of Alternatives

z_{mn} – Weighting of Alternatives with respect to a Criterion

% (Importance Rating) – Sum for criterion / maximum possible score

WSM & WSP

A_{WSM} – Most preferred Alternative

$R\left(\frac{A_K}{A_L}\right)$ – Ratio between two alternatives

Π – Product of…

A# **–** Cell reference in Excel

SMART

x_i – Ranking Value

a_{ij} – Performance of Alternative

AHP

z_{mn} – Pairwise Comparison weighting

λ_{max} – Principal Eigenvalue

ELECTRE

g_i – Set of Criteria

A – Set of Solution Alternatives

$a\boldsymbol{P}b$ – a is preferred to b

$a\boldsymbol{I}b$ – a is indifferent to b

$a\boldsymbol{J}b$ – a cannot be compared to b

$a\boldsymbol{Q}b$ – a is weakly preferred to b

q – Indifference threshold

p – Weak preference

$a\boldsymbol{S}_jb$ – a is at least as good as b

$\boldsymbol{C(a,b)}$ – Concordance index

k – Subjectivity weighting

θ – Concordance index when the value is neither 1 nor 0

PROMETHEE

$d_j(a,b)$ – Deviation between two alternatives for a criterion

$P(a,b)$ – Preference for a over b

$\pi(a,b)$ – Level of preference for a over b

Φ^+ – Positive Outranking Flow

Φ^- – Negative Outranking Flow

$\Phi(a)$ – Net Ranking Flow

1. Introduction

1.1 Background

With the population of the world increasing at a rate of 1.2% until 2025 (United Nations 2013) and already over seven billion, the amount of land available to deal with waste disposal is ever decreasing, thanks to demand for housing, businesses and many other enterprises. For this reason, action needs to be taken to keep the space taken by landfill as low as possible, with a view to phasing out their use. Methods of reducing, reusing and recycling/composting are increasingly being used to achieve this ultimate goal across the world, and more specifically within the European Union (EU). Wales, as a part of the United Kingdom (UK), has agreed very challenging incremental targets to aid the European objectives that have been set, with a view to achieving 100% of waste being diverted away from landfill by 2050 (WAG 2009). The decision making process behind the methods which will achieve these targets is something that rarely comes in to focus. Thanks to a results driven environment, the emphasis is usually placed on the economic impact, whereas the increasing rhetoric of global discussions is that the environmental issues are addressed. Therefore, the question is which out of economic, environmental, social and technological impacts, are the most important and how is a well-rounded solution in terms of waste management achieved?

Waste has been defined in the same way for at least thirty years in the following, as defined in Article 3(1) of the revised Waste Framework Directive (rWFD) (2008/98/EC) as,

"… any substance or object which the holder discards or intends or is required to discard…"

Municipal waste is defined in the Landfill (England and Wales) Regulations (2002) as,

"…waste from households as well as other waste which because of its nature or composition is similar to waste from households."

With rising quantities of municipal waste generation in the European Union (EU), the need for monitoring was introduced, for which Eurostat was created. Eurostat was created in 1959 as a Directorate- General of the European Commission to provide statistical data to the Member States of the EU and homogenise the statistical methods used in everything from population conditions, to economics, to environmental and energy data (Eurostat 2013b).

Waste itself can be categorised into a few main areas as shown in Figure 1.1, which shows the total waste generated by the 27 EU Member States for 2010. There are three broad areas of waste which are categorised as Municipal, Industrial and Commercial (C&I), and Construction and Demolition (C&D). Eurostat go further than the Landfill Regulations in defining municipal waste for the purposes of reporting data as:

> *'Municipal waste is mainly produced by households, though similar wastes from sources such as commerce, offices and public institutions are included. The amount of municipal waste generated consists of waste collected by or on behalf of municipal authorities and disposed of through the waste management system.'* (Eurostat 2012)

Municipal waste is now referred to as Local Authority Collected Waste (LACW). It can be seen that construction waste takes up a large percentage, just over a third, of the overall waste generation in the EU, whereas household waste (generally the majority of municipal waste) accounts for about 11%, with 220 million tonnes generated. All other sectors can be loosely categorised under Commercial with Industrial Waste, making up the remainder.

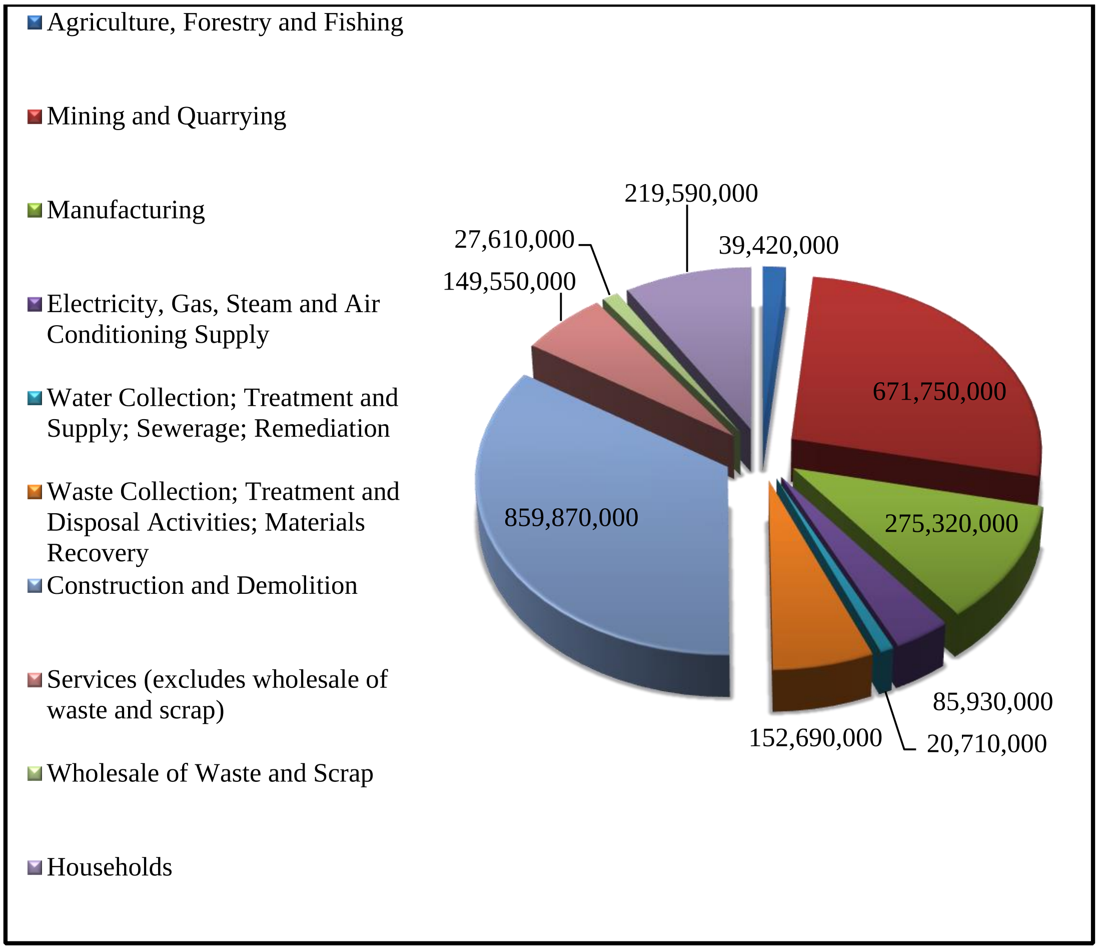


Figure 1.1 - Waste generation in the EU27, by category, for 2010 – all weights in tonnes. Total tonnage (excluding Mining and Quarrying) is 1.83 billion tonnes (Eurostat 2014)

In the UK, Figure 1.2 displays waste arisings that are composed of 11% municipal waste, 48% from C&I and 41% of all waste is from C&D, as of 2010. Although the C&D and C&I percentages between the EU and the UK differ, the Municipal Waste percentages are very similar and more importantly, are a relatively low percentage of waste generation. This raises the question, why is there so much emphasis placed upon dealing with municipal waste, when any change will have a low impact on the total waste generated?

One reason for this is because LACW directly affects the general public through their being generators. The waste they generate is usually collected by a local authority (LA), and therefore their responsibility, having direct contact with householders. Following the financial crisis that started in 2008, public budgets are squeezed (Callan et al. 2011) and LAs have to implement EU Directives in the most efficient way possible (EEA 2013).

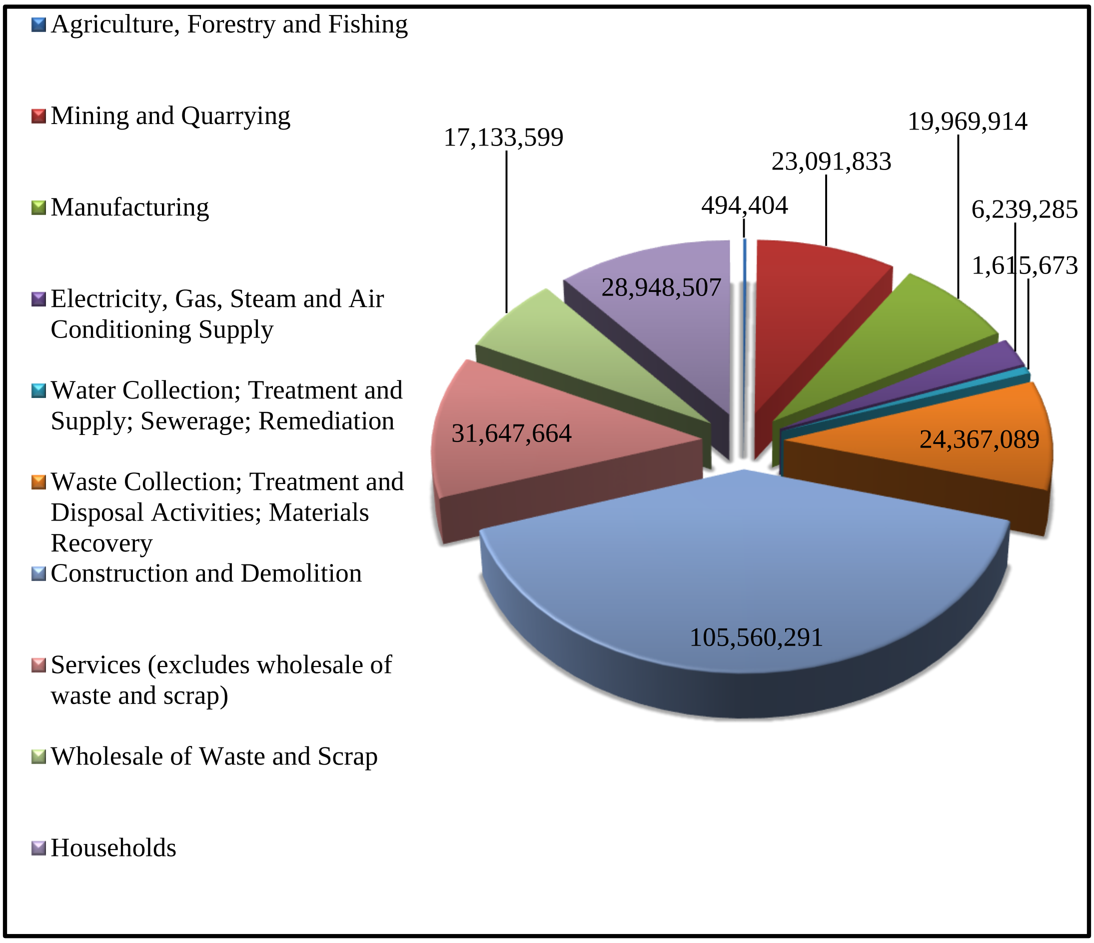


Figure 1.2 - Waste generation in the UK, by category for 2010 – all weights in tonnes. Total (excluding Mining and Quarrying) is ~236 million tonnes (Eurostat 2014)

As will be outlined later in this chapter, the rWFD also lays out specific goals that must be achieved from the recovery of municipal waste by 2020 by all Member States.

Figure 1.3 shows that the amount of municipal waste generated in the whole of Europe increasing from 1995, at 474kg per capita, to its maximum in 2002 of 527kg per capita. The Landfill Directive was introduced in 1999 (1999/31/EC) to reduce the amount of waste being sent to landfill. The effects were not felt until 2002 (which coincides with the inception of the Landfill Regulations in the UK), suggesting that the Directive took about 3 years before being widely transposed into primary legislation for the individual Member States of Europe. Figure 1.3 shows that since 2006, there has been a steady decline in the tonnage of MSW generated to below 500kg per capita. It was assessed that there was an average of 492kg of municipal waste produced per capita in the EU member states in 2012, totalling approximately 250 million tonnes of LACW (Eurostat 2013a). Comparatively, the UK was producing an estimated 498kg per capita in 1995, increasing to just over 602kg per capita in 2004. By 2014 the per capita production for the UK was…

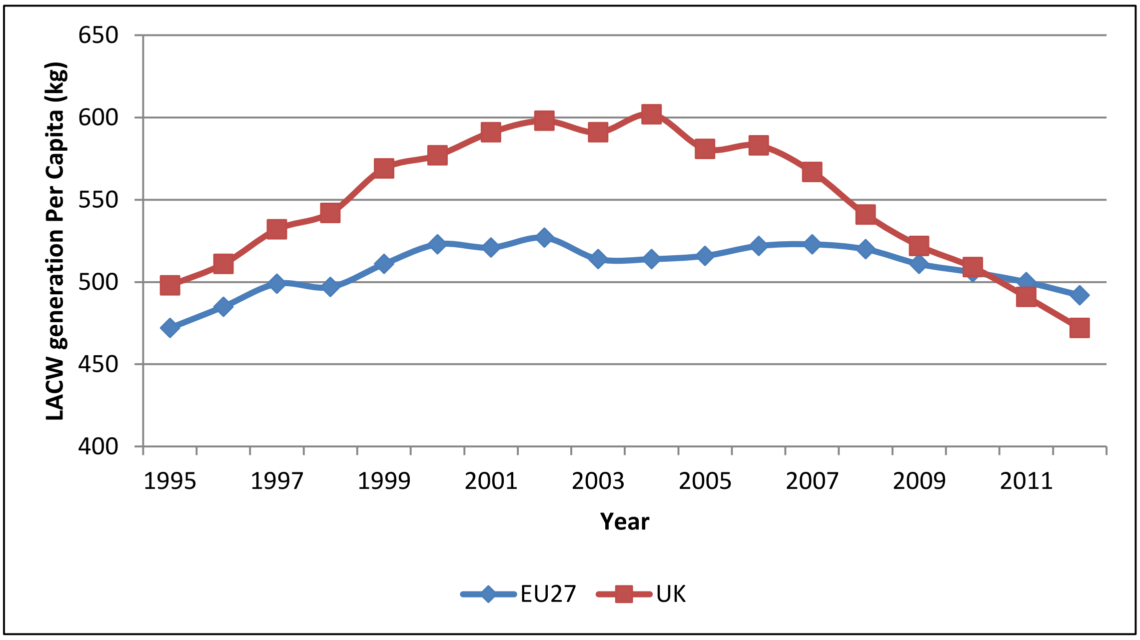


Figure 1.3 - Waste Generation of Municipal Waste in Europe and UK from 1995 – 2012, kg per capita (Eurostat 2014)

Figure 1.4 shows some of the countries that contributed to the EU statistics. It would be expected that the majority would show a trend of increasing waste arisings until 2002 before decreasing the amount of waste they generate, however in reality this varies wildly. Scandinavian countries appear to have increased their waste generation until 2008 before bringing it down closer to 2000 levels by 2012. The Mediterranean nations show a general increase in the amount of waste generated over the period shown, except for Spain which have severely reduced the production of waste by 2012. Whilst in general, the central European countries have kept their tonnages fairly similar. Comparatively, the UK shows a similar trend with the Scandinavian countries by increasing the tonnage of waste between 1995 and 2000 from 498kg to 577 kg per capita, before steadily reducing the amount of waste created to 472kg per capita in 2012. The figures for the UK fall in line with the introduction of European legislation and their subsequent transposition into State law alongside the various other European States' legislative framework, to combat rising levels of LACW generation.

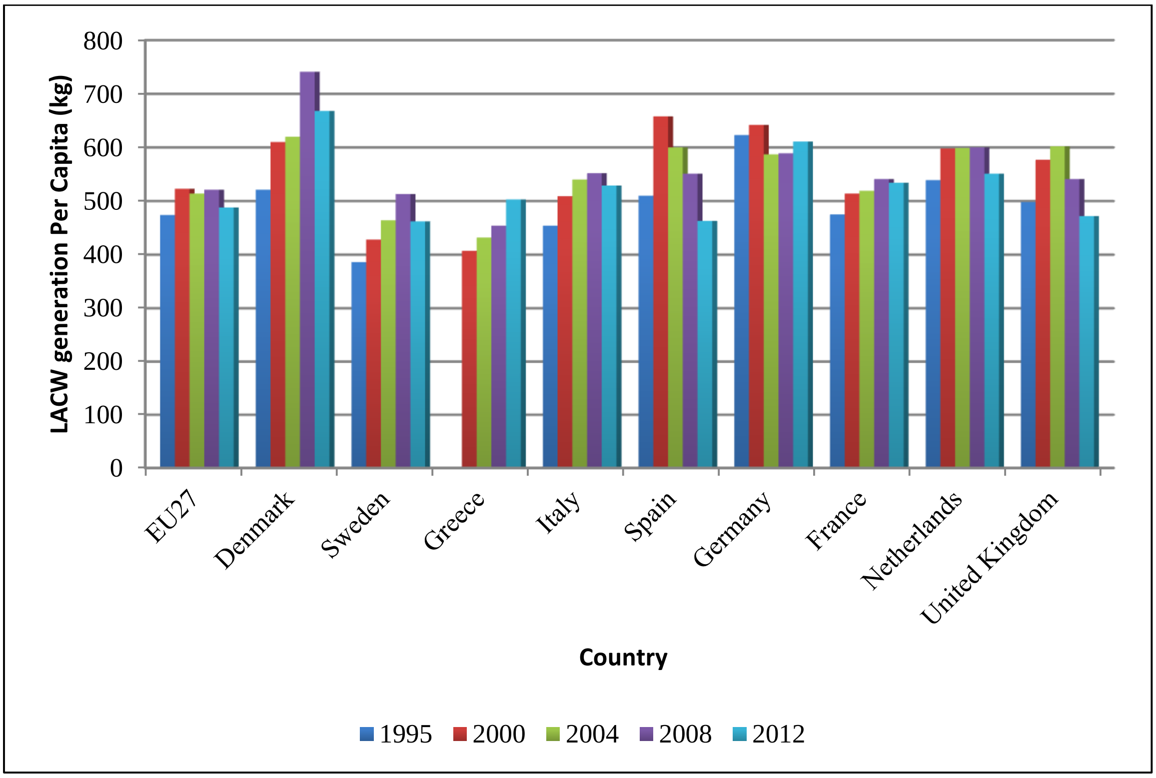


Figure 1.4 - Waste Generation in Europe from 1995 -2012, kg of LACW per capita (Eurostat 2014)

LACW is only a part of the total waste generated in the EU, which totals at around 2.3 billion tonnes in all sectors (Eurostat 2013c). Although MSW only represents a small fraction of the overall waste produced, it is the responsibility of the public sector. With increasing budgetary pressures being applied to all member states following the 2008 economic downturn, there was a large importance placed on finding the most efficient way to manage MSW.

1.2 Directives and Regulations

When applied to waste management, historically in the EU and UK, it has been easier and cheaper to landfill waste than to make a concerted effort to minimise the amount of waste produced and/or increase recycling and recovery rates (DEFRA 2009). The standard rate of the landfill tax in 2003/4 was £14 per tonne compared to £80 in 2014/15 per tonne, (Eunomia and WRAP 2015). With increasing environmental strains, such as the destruction of the ozone layer and climate change, such legislation was required to change anthropological effects on the environment. The remainder of this chapter outlines the legislation that has been created to do so and the effect this has on the UK and Wales and it's Local Authorities (LAs).

Every country that is a Member State of the EU deals with the legislative framework set at the European level, in a different manner. The UK, as a whole, is scrutinised from an EU perspective. Further to this, it is composed of devolved governments for Northern Ireland, Scotland and Wales (Cabinet Office 1998; Cabinet Office 2006). This means that each country has been granted powers, in certain areas, to set their own legislation, including waste management.

The Waste Framework Directive was, relatively speaking, a very basic overarching strategy in the mid 70's. It has now led to many other Directives that cover more specific waste streams such as electrical and electronic waste, oil, hazardous waste, batteries and many more. This is to ensure that all MSW is dealt with in a homogenous way across the whole of the EU and the Directives are then implemented by member states through national or primary legislation. To give a Directive force, legislation pertaining to the UK must be transposed into domestic law, through the use of Regulations, and Measures in Wales now that it has a devolved Government, are required to generate primary legislation. Table 1.1 shows the current list of relevant UK legislation and the European Directives that they have enacted. Whilst this is a non-exhaustive list of legislation relating to waste management, it is a representation for the amount of legislation that LAs have to comply with, to achieve their targets. Those listed in Table 1.1 have all had revisions and amendments that LAs must keep up to date with, to be able to change their methods of collection accordingly.

Table 1.1 - Table of UK legislation following from EU legislation

EU Directives	UK Legislation
Waste Framework Directive (1975–2008)	Environment Act 1995 The List of Wastes (Wales) Regulations 2005 Clean Neighbourhoods and Environment Act 2005 The Waste Management (England and Wales) Regulations 2006 Producer Responsibility Obligations (Packaging Waste) Regulations 2007 The Site Waste Management Plans Regulations 2008 The Waste (England and Wales) Regulations 2011 The Controlled Waste (England and Wales) Regulations 2012
Landfill Directive 1999	Pollution Prevention and Control Order 2001 Landfill Regulations 2002 The Landfill Tax Regulations 1996 The Environmental Permitting (England and Wales) Regulations 2010 The Landfill (Maximum Landfill amount) Regulations 2011
WEEE Directive 2012	The Waste Electrical and Electronic Equipment Regulations 2013

1.2.1 The Waste Framework Directive and its revisions

The Waste Framework Directive (WFD) first came into being in 1975, laying out the basic need for a reduction in the amount of waste generated and its harmfulness, through product manufacturing and techniques for final disposal (75/442/EEC). It also states that the recoveries of waste through re-use and recycling of waste should be encouraged, alongside the use of waste as a source of energy, creating the beginnings of the waste hierarchy. The WFD has been amended many times since 1975, with the most recent in 2008 and is referred to as the rWFD (2008/98/EC), where most notably the waste hierarchy is distinctly outlined and defined. Figure 1.5 shows a graphical representation of the hierarchy, as outlined in Article 4(1) of the legislation, which is widely used throughout the waste management sector. Although it is listed in the rWFD, it can usually be found in this form of a pyramid or inverted, as an easy to use reference for the order of priorities of dealing with waste.

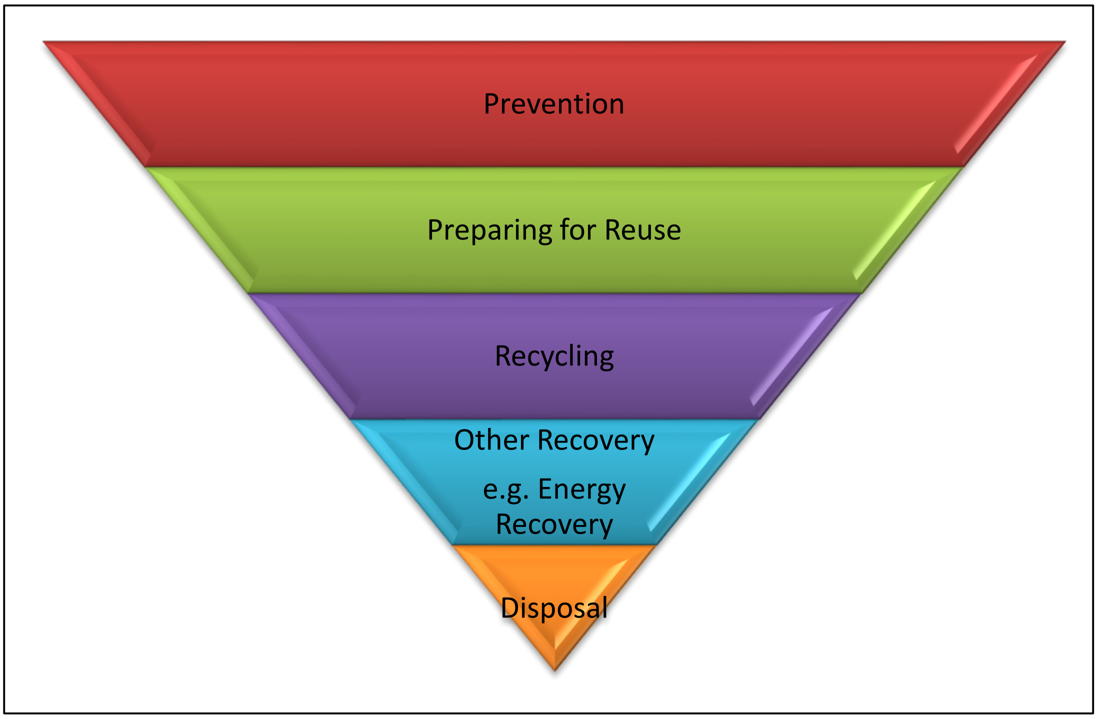


Figure 1.5 - Waste Hierarchy Pyramid adapted (2008/98/EC)

The emphasis of the hierarchy is that the best overall environmental outcome from the measures taken should be encouraged. If this requires moving away from the hierarchy, where justified with life cycle thinking, the rWFD Article 4(2) allows for this (2008/98/EC).

What is not highlighted in the pyramid is the producer's responsibility to decrease the amount of environmental impact in the design of their product, and where this is not possible, they must pay for the externality created. This idea was first formally introduced by Thomas Lindhqvist in 1990 (Lindhqvist and Lidgren 1990) for the Swedish Ministry of the Environment and further developed in his doctoral thesis (Lindhqvist 2000). It is considered necessary, to account for the life cycle costs involved in the production and subsequent pricing of a product. This is dealt with in Article 8 of the rWFD and explicitly outlines how the producers must take the burden of responsibility and inform waste handlers of the best method for disposing of materials.

After the producer responsibility is accounted for, prevention and minimisation is the first cause of concern for those in the waste industry, as a reduction in the amount of waste created eases the burden on LAs. A reduction in the volume or mass of waste indicates that the householders are thinking more about what they use and how to avoid virgin materials being consumed. If items cannot be prevented from becoming waste, then re-use is the next favoured option, meaning that the waste in question is refurbished if necessary and use for the same purpose it was used for originally.

Where reuse is not possible, recycling of waste is next to be considered. This involves the reclaiming of and repurposing of materials for a new use, e.g. where recycled office paper is subsequently used as newspaper. Recycling of waste is the most widely advertised and used waste handling option, with the LAs main focus being on this area and the decisions required for the best method of recycling constantly being challenged.

Other recovery of waste can mean one of a few options, but the most common is the incineration of waste to retrieve energy and heat from residual waste. This is preferred over immediately landfilling the residual waste, as it reduces the volume and mass of the materials whilst also allowing for energy, heat or any other type of recovery thus avoiding the use of fossil fuels for such reasons. The final option, if none of the above can be carried out, is to landfill the residual collection, which is the least favoured of all approaches.

The rWFD highlights that waste should be collected separately (Article 3) and undergo recovery operations (Article 10) where it is "…*technically, environmentally and economically practicable* (TEEP) *and shall not be mixed with other waste or other material with different purposes*" (2008/98/EC). It also states that by 2015, all Member States must have implemented separate collection of plastic, paper, metal and glass, and by 2020 the preparation for reuse and recycling of these and any similar household-like waste, must be at least 50% by weight. At the time the rWFD came into being in 2008, the average recycling rate across the European States was ~23% (Eurostat, 2014) meaning that the Member States of the EU were required to increase their recovery of materials at a minimum rate of just over 2% per year.

In Europe, as at 2012, the weight of municipal waste generated decreased by 12.5 million tonnes to 246.6 million tonnes, whilst recovery (excluding incineration) increased by 6.7 million tonnes to 65.9 million giving a rate of 27% by weight (Eurostat, 2014). Although the UK and other Member States of the EU have made large increases in the levels of recovery, other States such as Slovakia, Romania and Poland who joined the EU in the last ten years, have not been subject to EU Directives as stringently as those who have been a part of the EU for longer. This has kept the overall average down, causing a large shortfall in terms of the target required, of reaching 50% diversion by 2020 (2008/98/EC).

to Regulations and Measures (for Wales) on a constant basis, as presented in Table 1.1.

1.2.2 Technically, Environmentally and Economically Practicable Collection of Recyclate

To specifically transpose Article 10 (2) of the rWFD, UK Government amended Waste (England and Wales) Regulations 2011 in 2012. This was to introduce into the UK legislative framework, the separate collections of waste paper, metal, plastic and glass are to be carried out so long as it is Technologically, Environmentally and Economically Practicable (TEEP) to do so (DEFRA 2012). The amendment also reiterates, from the rWFD, that this must be done pursuant to following the waste hierarchy (Article 4) and without a negative effect on the environment (not releasing more greenhouse gases) (Article 13).

The difficulty faced is the slight ambiguity in the definition of ‘separate collection of paper, metal, plastic and glass’. Does this mean that they can be collected in a commingled form which is all together, but separate from residual and food waste? Or does this mean they must be source segregated and collected separately from each other in the first place? The answer was provided through the Judicial Review that was passed in March 2013. The explanation for TEEP was given thus (R (on the application of UK Recyclate Ltd) v Secretary of State for the Environment Food and Rural Affairs 2013):

‘Technically practicable’ means that the separate collection may be implemented through a system which has been technically developed and proven to function in practice.

‘Environmentally practicable’ should be understood such that the added value of ecological benefits justifies possible negative environmental effects of the separate collection (e.g. additional emissions from transport).

‘Economically practicable’ refers to a separate collection which does not cause excessive costs in comparison with the treatment of a non-separated waste stream, considering the added value of recovery and recycling and the principle of proportionality.”

This means that so long as there is thorough and clear documentation that the collection method complies with TEEP standards, and therefore the WFD, then either method of collection is viable.

In April 2014, Welsh Government launched a TEEP guidance Consultation document entitled *‘Consultation on Draft Statutory Guidance on Separate Collection of Waste Paper, Metal, Plastic and Glass’* (Welsh Government 2014). The document reinforces the message passed in the rWFD of TEEP and gives the explanation for what is meant by each element and a non-exhaustive list of examples where Waste Collection Authorities (WCA) may consider diverging from the Waste Hierarchy:

- Cost – The cost of implementing a new method must be compared with the possible savings and the subsequent pay-back period.

- Congestion of streets, flats and houses – Having a full kerbside sort involves many containers and where they are causing congestion, may render the system not practicable.
- Very dispersed communities – This may cause the collection to not be economically practicable thanks to high collection costs for low yield. (Welsh Government 2014)

The consultation asks whether the reader considers that the statutory guidelines set out clearly, how the Welsh Government has implemented Regulations 13 and 14 of the Waste (England and Wales) Regulations 2011 and its amendment.

1.2.3 The Landfill Directive

By 1999, the Council of the European Union stated that not enough was being done to encourage waste prevention through recycling and recovery of waste material. The main areas of concern were to reduce the extraction and use of primary raw materials and divert waste that still has economic value, from being sent to landfill. In addition, the dry recyclables, food and biodegradable waste were all untreated and the potential benefits from their processing, were not being realised. The Directive on The Landfill of Waste (Landfill Directive) (Council of the European Union 1999) was brought into being, in 1999 to:

"...prevent or reduce as far as possible negative effects on the environment, in particular the pollution of surface water, groundwater, soil and air, and on the global environment, including the greenhouse effect, as well as any resulting risk to human health, from the landfilling of waste, during the whole life-cycle of the landfill" (1999/31/EC).

The Landfill Directive set the following demanding targets for the disposal of biodegradable waste:

- By 2006 reduce the biodegradable waste landfilled to 75% of that produced in 1995.

- By 2009 reduce the biodegradable waste landfilled to 50% of that produced in 1995.
- By 2016 reduce the biodegradable waste landfilled to 35% of that produced in 1995.
- Any Member State that placed more than 80% of their collected MSW in 1995 into landfill, may postpone the targets by up to 4 years.

The Landfill Regulations (Government 2002) primarily set out pollution control regimes for landfills concerning planning permission and associated permits, especially when pertaining to hazardous, non-hazardous and inert wastes. It outlines the controls for the nature of waste accepted for each of these three varieties of landfill and what can and cannot be accepted, e.g. no liquid waste, clinical waste or whole used tyres, in Articles 4 to 6, to comply with other EU Directives. The remainder of the Directive covers permitting allowances and regulation, cost during operation and after closure of the landfill and the obligation of the Member States to report back to the EC every three years (1999/31/EC).

This has since been updated and it was stipulated that the amount of municipal biodegradable waste sent to landfill had to be reduced considerably and when transposed into UK law, the Landfill (England and Wales) Regulations (2002) were formed. These Regulations were a direct transposition and outlined all of the above and also the general requirements in specification of a landfill and its monitoring procedures.

1.2.4 Landfill Tax Regulations

The Landfill Tax Regulations (1996), and numerous amendments, act as a financial disincentive for LAs to landfill as the more materials are reused or recycled, the amount of waste being sent to landfill decreases, thereby reducing the amount of tax paid by the Waste Disposal Authority. Additionally, the positive publicity that the LA would receive from saving the tax payer money and improving the environment, due to a reduction in pollution and energy savings from waste diversion, acts as an initial driver to help achieve targets that have been set. Once the public are recycling more and aware of all that a LA is doing to aid householders and businesses environmentally, the potential monetary gains can be identified.

Although the Landfill Tax Regulations aid the reduction of waste being sent to landfill, it was not coherent to the point where the income gained from this legislation can be truly directed to focussing waste management in a holistic way (Morris et al. 1998). Since Morris et al. findings, these have been addressed further, no more so than in the Landfill Regulations, to bring all the legislation that was covered under differing Acts, Bills and Regulations, under 'one roof'. This highlighted under Schedule 5 of the Landfill Regulations (2002) which lists the amendments made to previous legislation in its formation.

1.2.5 Welsh Legislation

Through the devolution of the Welsh Government in Wales, the transposition was originally addressed under 'Wise About Waste – The National Waste Strategy for Wales' (WAG 2002). Whilst not necessarily becoming legislation, it gave direction for future Welsh policies. 'Wise About Waste' flagged up an over-reliance on landfill as an increasing problem that needed to be dealt with (WAG, 2002). It was reiterated that measures needed to be introduced to reduce reliance on landfill and start using waste as a resource. 'Wise About Waste' outlined the following, to comply with the European framework:

- By 2003/04, 15% of municipal waste must be recycled/composted (with a minimum of 5% being recycled and a minimum of 5% of source segregated materials being composted)
- By 2006/07, 25% of municipal waste must be recycled/composted (with a minimum of 10% being recycled and a minimum of 10% of source segregated materials being composted)
- By 2009/10, 40% of municipal waste must be recycled/composted (with a minimum of 15% being recycled and a minimum of 15% of source segregated materials being composted)

These targets were exceeded with percentage values of 17.7% in 2003/4, 29.9% in 2006/7 and 40.4% in 2009/10 (Howarth 2011)

Welsh Government further added to the legislative pressure on LAs with an overarching waste strategy for Wales entitled 'Towards Zero Waste, One Wales: One Planet' (referred to as the 'Towards Zero Waste' in the remainder of this thesis). The strategy aims for '100% recycling, no residual waste and no energy from waste' (WAG 2009) by the year 2050. Figure 1.6 was included in this document and shows the changes that were made since Wise About Waste was introduced. In 2002 there was a rate of 8.4% for recycling carried out by Local Authorities. Just over 1.5 million tonnes of an estimated total ~1.75 million tonnes was sent to landfill and recycling and composting constituted the remaining 250, 000 tonnes. However, over the seven year period, similar to the whole of the UK, the tonnage of waste going to landfill steadily reduced whilst the weight of material recycled/composted steadily increased, coupled with an overall reduction in waste arisings. By 2005, the amount of MSW sent to landfill reduced by approximately 200,000 tonnes and recycling had increased from approximately 150,000 tonnes to 350,000 tonnes. By 2008-09, MSW being sent landfill was approximated at just above the 1 million tonne mark, waste to energy started to be utilised and recycling and composting had reached about 38% with about 650,000 tonnes being processed.

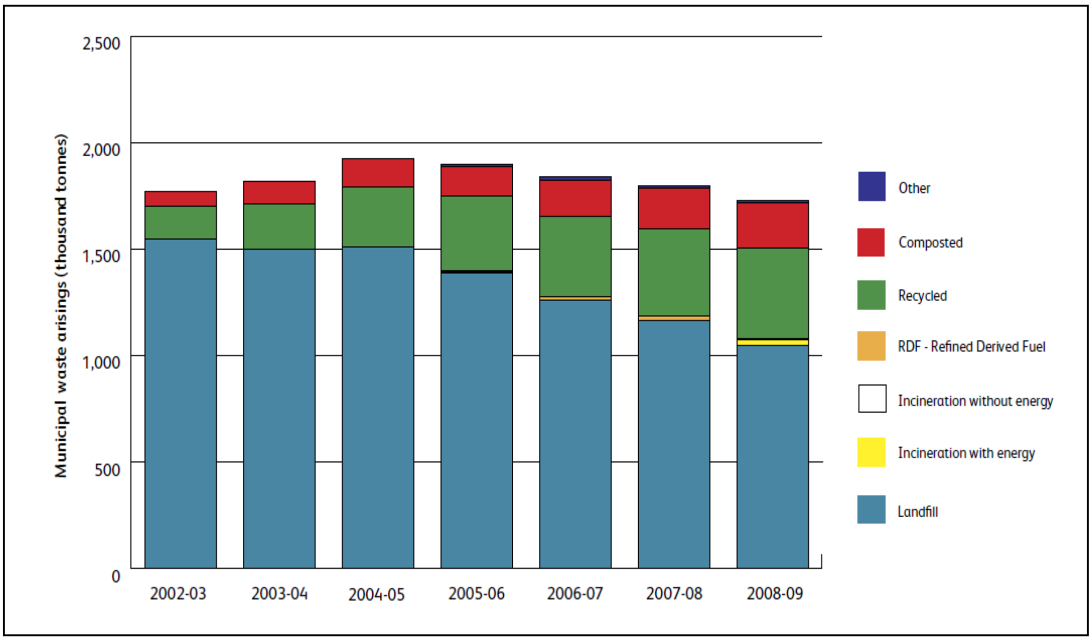


Figure 1.6 – Municipal Waste Management in Wales from 2002 – 2009 (WAG 2009)

Following on from the overarching strategy, Stats Wales (2014) reported that as of 2014, the recycling, preparation for reuse and composting (or similar treatment) rates were:

- 2009/10 – 40.5%
- 2010/11 – 45.3%
- 2011/12 – 50.0%
- 2012/13 – 52.3%

The Waste (Wales) Measure (2010) outlines and places into legislation, the more challenging recycling rates that were agreed in the creation of the Towards Zero Waste Strategy, than those originally stipulated at a European level. The remainder of the Waste (Wales) Measure 2010, transfers the powers to Ministers to be able to create and control legislation for Wales to set and monitor targets, penalise the LAs who do not meet them, regulating landfill use and also planning controls (Waste (Wales) Measure, 2010). The more stringent targets laid out in this measure are:

- 58% recovery (recycling, preparation for re-use and composting) by 2015/16
- 64% recovery by 2019/20
- 70% recovery by 2024/25

It can be seen that these recovery rates include a large jump from the targets outlined in Wise About Waste. By 2009/10, it was required that 40% of waste should be recovered, whilst by 2015/16 58% must be recovered. This represents a step change in the drive forward for the diversion of waste from landfill that reflects the seriousness that Wales places on this matter.

To achieve these targets and drive a sustainable waste economy forward, LAs needed to change their longstanding modus operandi from the default of black bag residual collection and sending this waste to landfill. Using a one receptacle, black bag collection was the easiest method of waste collection for householders. Introducing a new collection scheme would require more effort on their behalf and therefore be less likely to change their habits (Wilson and Williams 2007). The need arose to create campaigns encouraging businesses and the general public to see the potential savings that could be made in recycling and reducing waste creation, along with the extra benefits of diverting waste from landfill (Miranda et al. 2013).

Although there are numerous Directives at a European level, Regulations at UK level and Measures for Wales, are regularly amended or new legislation is added. For a LA there is uncertainty in the changes to legislation that will impact upon their operations. For example, should certain waste streams be added to the list of mandatory streams? Will the LA have the scope to adjust their infrastructure or collection method? This makes long term planning exceptionally difficult and mostly possible to plan in the short term. Both of these issues, amongst others, indicate that the LA will struggle to have all the information possible to make informed decisions. It is this uncertainty that causes the LA to require a robust decision making method that can be easily followed and uses as much of the information available, to its maximum potential.

With the many drivers and barriers that LAs face, the conflict about which method of collection to use, either source segregation or commingled collection, and which is acceptable according to the WFD, creates many decision based challenges.

1.3 Waste management and Materials Recovery – The Challenges for Local Authorities

For a local authority, collection of household waste is a duty to avoid a build-up of waste in their locality. For the collection of waste, there are many options available to a collection authority, of which the original type was a single household collection. All household waste would be placed into this one bag, collected and subsequently sent to landfill, thereby bypassing any opportunity to recover any materials or energy potential from the waste.

As outlined above, this was not a sustainable approach to waste management and legislation has been the main driver for change. But beyond legislation, what other factors influence a LA in deciding how to tackle this issue?

1.3.1 Diversion from Landfill

The primary driver for general waste diversion from landfill is the environmental benefit gained from reducing pollution of the land, possibly of water courses and the air through production of harmful greenhouse gases. On top of this, there is a financial gain through the avoidance of paying gate fees to dispose of the waste, levied via landfill taxes. If the message is properly advertised that diversion is happening, this can have a positive effect on publicity to the general public and encourage them to participate more (Quested et al. 2013).

Equally, there is an added cost associated with recovering waste instead of landfilling all materials. Firstly, facilities must be set up and maintained to carry out the recovery procedures incurring a large capital cost. Gate fees are a cost consideration and more vehicles and employees are required to collect, transport and sort the separated waste streams to/at the respective facilities.

1.3.2 Reuse and Preparation for Reuse

When considering reuse and the preparation for reuse of waste, the main benefactors are non-governmental companies that receive clothes, bulky waste, electrical items and many other categories of waste, and can refurbish them. Many of the general public already participate in reuse without realising they are doing so and avoid waste, in donating items to the likes of Oxfam, The British Heart Foundation and many other charity shops that can be found on the high street. For this reason, it does not take much more input from the LA, although many work in conjunction with the third sector to try and increase rates, an example of which is Fylde Council in the north west of the UK (Fylde Council 2014). Here, the council work in partnership with two charities, Helping Hand and Refurb, who reuse and recycle old furniture. For a small charge, within 3days of a request being entered they will collect large household items such as fridges, cookers and furniture (bulky waste) to prepare for reuse.

On the other hand, whilst the landfill tax has been set with a floor value of £82.60 per tonne for 2015 (HM Treasury 2014) it is still not prohibitive enough to force an even higher level of reuse, to avoid materials becoming a waste.

1.3.3 Food and Green Waste

When considering food and green waste there are accompanying drivers and barriers in composting or digesting such refuse. The gases that are created through aerobic composting or digesting can be collected for use as a fuel or similar needs. At the same time, this can be done with little odour and destroy pathogens (Siegmeier et al. 2015) that can be created if left with other residual waste. Anaerobic digestion also provides renewable energy in methane production (DEFRA 2011a)

However, composting requires a large amount of space to be carried out effectively and is a slow process taking around 12 to 36 weeks (Gutiérrez et al. 2015) for the process to be completes. In the digestion of food waste, this requires specific temperatures with a process that must be constantly monitored by experts in this specific field.

1.3.4 Recycling

The drivers behind why a LA should carry out recycling are initiated from the decline in available landfill space and its associated environmental harm. Recycling aids the removal of a large volume of waste that would otherwise be destined for landfill.

The LA faces uncertainty in the future of waste management in two major areas. The first is that it is also impossible to predict how the market will change with time. As this works on a demand and supply basis, a LA cannot know for certain which waste streams, when recycled, will give them a significant financial return to make a practicable decision. They need to have flexibility to deal with market fluctuations which suggests inherent uncertainty and impacts upon the decision, by not being able to invest in the most appropriate infrastructure.

The potential income that can be gained from reprocessed materials can be lucrative, especially for non-ferrous metals. Where the markets are doing well and offering a high price for a specific material this is shown below. Figure 1.7 shows that cast iron and zinc mixed scrap have a consistently high price at £750 and £500 per tonne respectively, meaning that a LA knows that they can expect a good return. It also shows that through a household collection scheme, the same can be expected from clear and a light blue PET and HDPE natural plastics with an average of about £215 per tonne collected. Equally, if the markets for recycled material are weak, then this becomes a barrier to recycling because there may be a lot of effort put in to access these materials for little return, or at a cost. In Figure 1.7 pots and trays show a consistent cost to the waste collector in disposing of them at £10 per tonne.

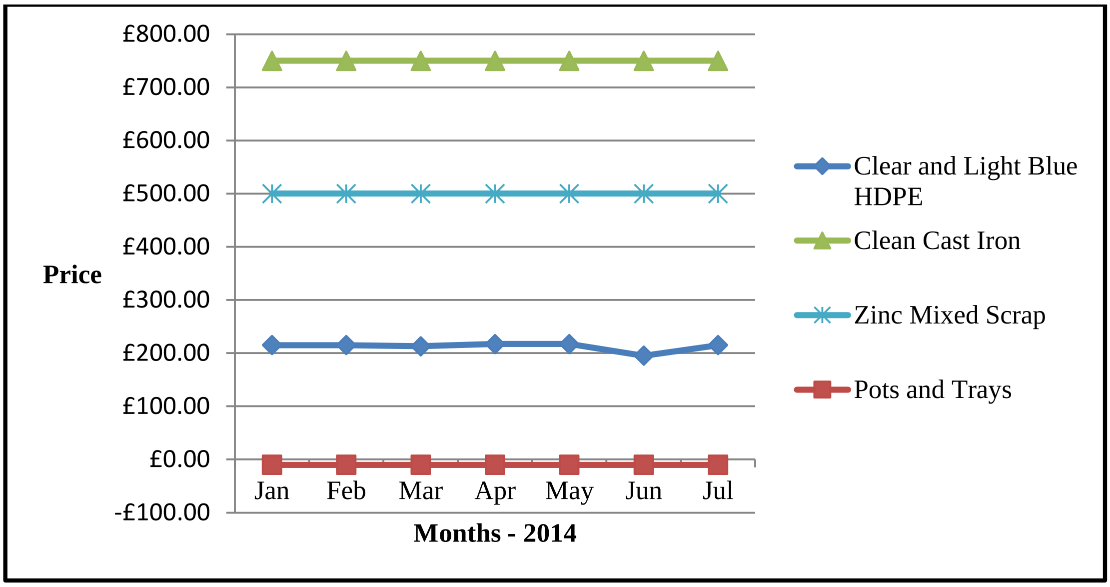


Figure 1.7 - Prices for Plastic and Non-Ferrous metal for 2014 (letsrecycle 2014)

The final consideration for a LA is if the price of the material fluctuates. Figure 1.8 shows the price that could be achieved for ferrous metals in the first half of 2014 (letsrecycle 2014). The price in January started at £200 per tonne and fell to £165 per tonne by February, presenting a difficult decision for the LA. As they do not know whether the price is likely to drop in the future or rise again, there is a difficult decision to make. As the price dropped further in the following months, to a low of £155 per tonne in July, the LA may combat this by stockpiling their goods until the market has recovered, and sell it on at a later date. An added driver for recycling is where recycled materials can be used to create products and packaging in lieu of the extraction of virgin materials, thereby reducing expensive and potentially environmentally unfriendly processes.

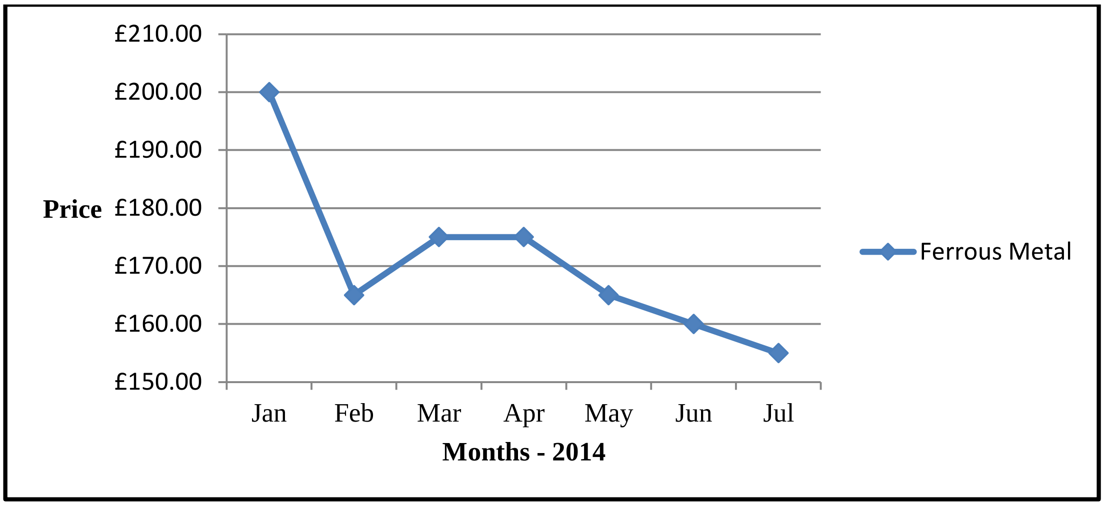


Figure 1.8 - Market Price for Ferrous Metal January to July 2014 (letsrecycle 2014)

However, public perception and non-participation in recycling schemes can hinder the progression of recycling rates. If householders believe that the waste they are separating is not being kept separate from residual waste, then they are likely to stop participating or lessen the extent that they do (Cole and Fieselman 2013). This misconception can come from seeing recycling bags and residual waste being placed into separate compartments in a split body refuse collection vehicle, but believing they are entering one container (Oakes 2014a). Also, if the system is too complicated, or perceived to be, then participation in a recycling scheme is likely to reduce. For authorities that have a large student presence, it can also be difficult to keep high capture rates as these students move in to the area for a year or two before moving on and may not know what is expected of them.

Linking back to whether the markets are either strong or weak, contamination can also play a large part. If recyclate is not cleaned or rinsed off to remove the majority of food stuffs, then the recyclate can become contaminated. Similarly, if non-target materials are entered in to the receptacle for recycling, it is classed as contamination and causes the need for further separation. This can reduce the value of the recyclate to be sold on to reprocessors and therefore cost the LA or severely reduce the income that can be gained.

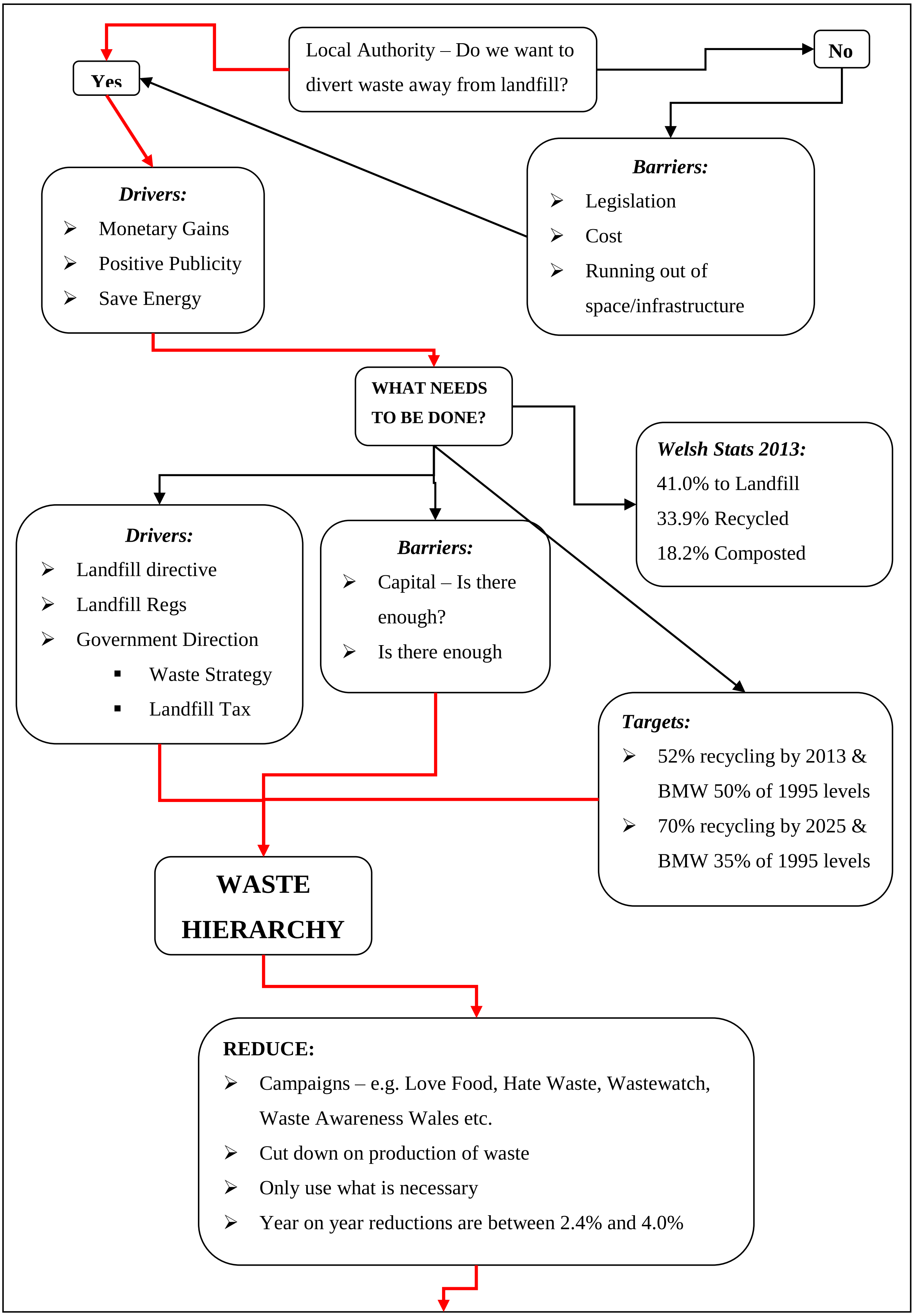
Figure 1.9 illustrates the drivers, barriers, targets and areas of concern. This diagram shows that there are many different elements that a LA has to contend with to minimise the amount of waste entering landfill. Consider that recycling is only part of the waste hierarchy, and it becomes clear that many factors affect the decisions made by LAs.

The ideal course of action is to divert waste from landfill. The infrastructure must be in place to enable this to happen whilst legislation drives the LA to make sure it does. Following this, the waste hierarchy must be followed as per Figure 1.5 and the flow chart in

Figure 1.9. Firstly a reduction in how much waste is produced in the first place must be implemented. This generally requires a nationwide campaign that pressures mainly product and packaging producers to reduce the amount used in the first instance. Also, focus is on householders to use only what is necessary and little attention is paid to LAs in this regard.

Reuse will influence mainly charitable companies, such as the British Heart Foundation and Oxfam as an example of well-known high street entities that enable reuse. Whilst landfill tax remains still cheap enough to be able to landfill many materials, there exists indifference for LAs to push the promotion of reuse. Although some LAs, such as Fylde Council, are partnered with third sector organisations, it may not directly benefit the LA to spend on such promotion or they may simply not have the funds available.

Recycling and the processing of biodegradable waste is the responsibility of the LA. However, it requires the participation of the public to allow the waste to be recycled with added worth.


Local Authority – Do we want to divert waste away from landfill?
Yes
No
Drivers:
Monetary Gains
Positive Publicity
Save Energy
Barriers:
Legislation
Cost
Running out of space/infrastructure
WHAT NEEDS TO BE DONE?
Welsh Stats 2013:
41.0% to Landfill
33.9% Recycled
18.2% Composted
Drivers:
Landfill directive
Landfill Regs
Government Direction
Waste Strategy
Landfill Tax
Barriers:
Capital – Is there enough?
Is there enough
Targets:
52% recycling by 2013 & BMW 50% of 1995 levels
70% recycling by 2025 & BMW 35% of 1995 levels
WASTE HIERARCHY
REDUCE:
Campaigns – e.g. Love Food, Hate Waste, Wastewatch, Waste Awareness Wales etc.
Cut down on production of waste
Only use what is necessary
Year on year reductions are between 2.4% and 4.0%

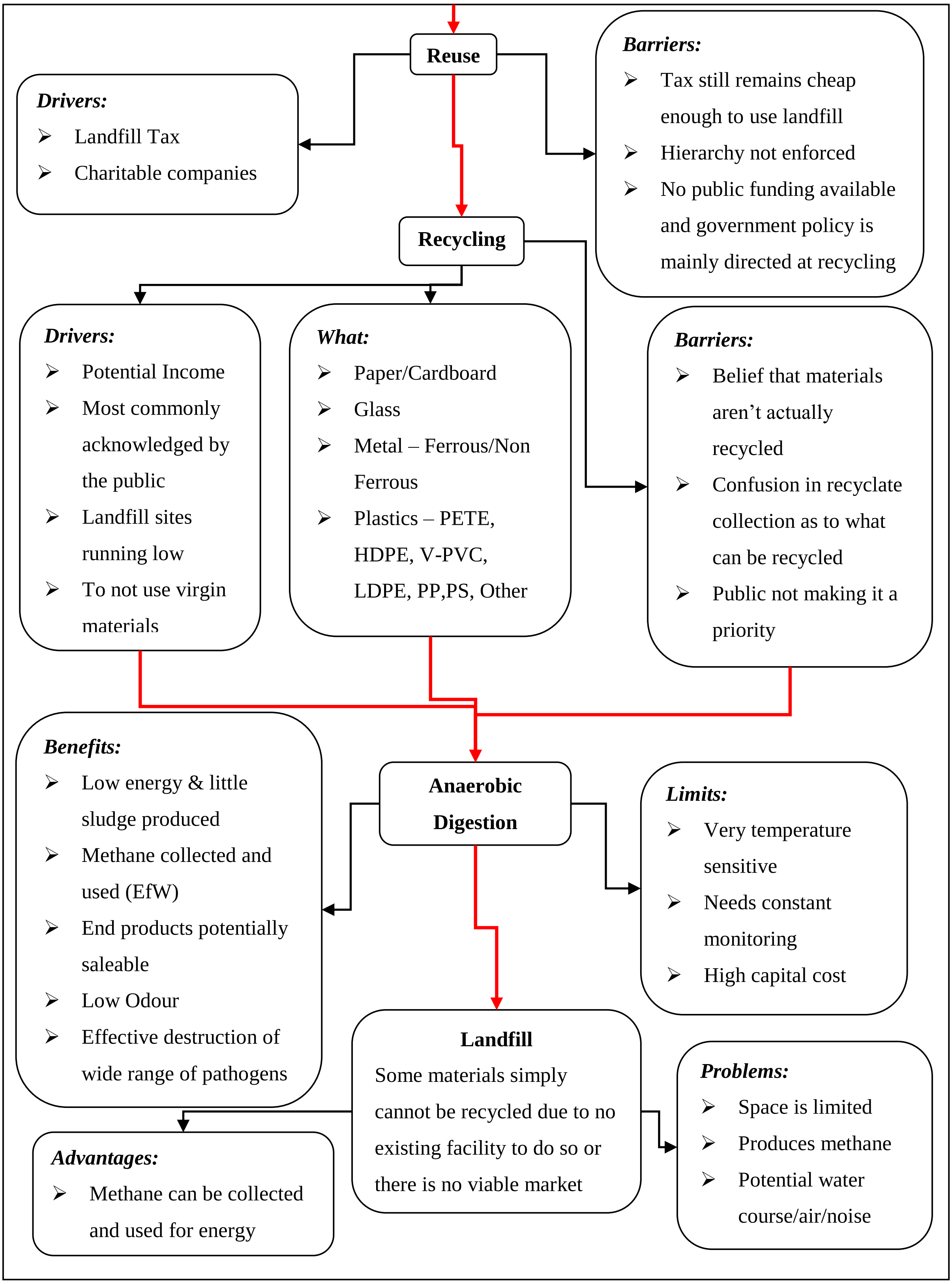


Figure 1.9 - Considerations for Local Authorities in relation to Recycling data taken from Statistics for Wales (2014)

A reason that waste material needs to avoid being sent to landfill is the environmental impact. When materials are left untreated, they decompose in an unorganised manner causing the production of methane, odour and potential air and water pollution. Although methane and leachate (liquid that has percolated through the waste and leached some of its constituents) can be collected and processed, they are unwanted by-products.

1.3.5 Current Methods of Recyclate Collection

With the drive for higher recycling rates, the method of collection has been expanded to accommodate separate dry recyclate collection in two main forms, with many variations. The use of a single receptacle or bag forms a commingled collection, where all recyclate is placed into it, so long as the authority can sort the recyclate at a Materials Recycling Facility (MRF). Any material that does not fall under this category must be placed into a residual waste bag or receptacle, which will be sent to landfill, or possibly passed through a 'dirty' MRF. A dirty MRF is used to extract any recyclate that may have been missed by the householder and has subsequently ended up in the residual waste. A kerbside sort approach entails numerous receptacles to be distributed to households so they can separate recyclate manually before collection. This places more of the onus on the householder, as they must segregate the recyclate waste streams into these receptacles. Usually, four receptacles will be provided to accommodate dry recycling (paper and card, metals, glass and plastics) as per the rWFD, article 11 (2008/98/EC) and further receptacles for food waste, garden and green waste and residual waste.

There are many permutations that can exist for the collection of recyclate which blur the rigid structure of commingled and kerbside sorting of waste. A commingled collection could be carried out with the extra separation of one type of recyclate and could be given the name of 'two-stream commingled collection'. Paper and card may be collected separately from all other recyclate, because at a MRF or in the collection process, they can easily become contaminated by broken glass or residual food stuffs and drinks that have not been rinsed and/or cleaned off from food packaging or drinks cartons, bottles and cans. Equally, glass may be collected separately, as the result of any breakages would cause contamination of all other recyclate material; this would also be considered as a two stream approach. Hence, there are advantages and disadvantages to both systems of collection as outlined below.

1.3.5.1 Kerbside Sort Collection

If a kerbside sort collection is introduced, the first benefit is the creation of new or more jobs. Thanks to the labour intensive nature of the work, having to sift through the material at the kerbside, rather than passing the recyclate through machinery at a MRF, more workers are required. This will be of benefit to the economy with, more money earned by (hopefully) local residents of the area leading to an injection of this money into the local community. This benefits the LA through positive publicity in securing more work for local residents.

By sorting the waste at the kerbside, the collection operatives can also leave immediate feedback to the householder by leaving behind undesired items in terms of recyclate. This aids the education of the general population, it can be argued, more so than a commingled kerbside collection. As the recyclate is taken away and sorted, the LA can only have a general overview of what residents are wrongly putting in their recyclate receptacle and cannot target those that need further education. With a kerbside sort, the householder can immediately see exactly what they should *not* put into the various containers. Alongside this, a higher quality recyclate can be collected thanks to source segregation meaning that the various fractions do not come into contact with each other and reducing the possibility of contamination.

A cost benefit of a kerbside sort collection is a lower level of investment required in infrastructure. Firstly, smaller collection vehicles are required, leading to lower fuel consumption, when compared to a Refuse Collection Vehicle (RCV). They are also more manoeuvrable than a RCV leading to easier collection of waste from small lanes and any roads that have a narrower width. Secondly, there is no requirement for a Materials Recycling Facility (MRF) and so, the LA does not need to invest in equipment and large buildings to accommodate such a facility. They do however need at least a transfer station or storage facility, to accommodate for the collection of recyclate.

The increased cost of having to hire more collection operatives than a commingled collection is a major consideration for a LA wishing to implement such a collection. This means that a larger workforce is required due to inspection of recyclate as well as more receptacles that need emptying onto the vehicle. To collect the same amount of recyclate (regardless of quality) as a commingled collection there is an increased labour cost. The collection vehicles themselves also have a limited volume capacity for the recyclate compared to the RCV as well. The 'bins' that hold the recyclate are more in number, however smaller in volume (WRAP 2008), leading to an increased number of trips necessary to a storage facility. This can increase the fuel consumption if these are not along the collection route.

A change in a kerbside sort system requires a great deal of new publicity for householders to understand what needs to be done differently from previous methods of collection, to keep effective capture rates high. This may also need a new receptacle to be delivered to all the households in the LA, which is another logistical and financial burden on the authority. Part of the reason for the increased need in promotional work is thanks to public perception. Householders may not be willing to recycle material if they are not confident in the use of a scheme. Many people cite the lack of space, time or knowledge to be able to recycle in a kerbside sort system, as well as having busy lives or children to look after for example.

From the perspective of a LA, a kerbside sort system may lead to lower quality recyclate being landfilled. The premise of the kerbside sort is that contracts can be created with those who reprocess the waste. This can lead to a higher price being demanded thanks to a higher quality of recyclate. If the contract states that a high quality recyclate is needed, then the LA will have no choice but to landfill the materials that do not achieve the necessary standards.

1.3.5.2 Commingled Collection

For a commingled kerbside collection the main benefits are twofold. Firstly, it was stated by Waste Resources Action Programme (WRAP) (WRAP 2008; Kinsella and Gertman 2008) that the absolute quantity of waste collected can be higher when compared to a kerbside sort collection and, in a quicker amount of time. This is most likely due to the collection operatives being able to pick up bags, after a cursory check that the items within are of the target materials, and place them into the RCV rather than having to sift through material extensively in a kerbside sort. When coupled with the ease for the householder of being able to place recyclate in one receptacle, studies suggest that the public are likely to place more items in for recycling than when having to source segregate (Garbett 2010; Miranda et al. 2011). The material collected can then be passed through the MRF to separate out unwanted material and the remainder passed on for processing.

The use of a MRF can also help increase the radius of collection thereby leading to less investment in infrastructure required. There are some councils in South Wales that use the same recycling facilities which in turn leads to economies of scale. The more material that is put through a MRF, the larger the output of recyclate that can be sold on, and the more that can be invested in the MRF itself for better technologies.

As touched upon previously, for the householder, a commingled collection can be less of a burden in times of change and in general use. A LA need only release promotional material advising of the changes required of the householder, who in turn must either stop or start including that new material stream. For example, aseptic packaging was challenging for many MRFs in the early 2000's due to its (general) composition of paper, polyethylene and aluminium mix, however many authorities now accept it as part of their commingled collection due to the introduction of hydropulping (separating layers of plastic and aluminium from cellulosic fibres through the use of water (Korkmaz et al. 2009).

1.3.5.3 What do the Local Authorities Currently Use?

Table 1.2 shows how the LAs of Wales currently collect their waste. It shows a consensus that there is not a 'one size fits all' approach. It shows that six LAs favour a kerbside sort and six LAs favour a standard commingled collection. The other ten have a variation of some description on the kerbside sort collection, commingled collection or 2 stream collections. This exemplifies that there are many complex decisions to be made for each authority.

Thanks to the varying types of pressures from drivers and barriers, and their magnitude of impact, there are discrepancies as to how they collect their waste. The two areas that are strongly agreed upon is the frequency of collection for recyclate, food waste and residual waste. Table 1.2 shows that food waste and recyclate are all collected on a weekly basis to encourage the use of the scheme; whilst residual waste is collected on a fortnightly basis, to discourage its use by householders. The only discrepancy is Gwynedd Council, which has decided to collect residual waste on a 3-weekly timescale to further discourage its use. This was implemented in October 2014 and was on trial, with a view to extending to the whole council area. If successful, it is likely to be implemented by other Welsh authorities, as it is claimed for Gwynedd Council will save £350,000 per annum (Roberts 2014). This has now been extended to the Meirionnydd area for further testing.

The collection of green waste is generally undertaken on a fortnightly basis, by ten LAs, one LA collects weekly and one does not collect green waste at all. The remainder have an opt-in system that requires the householder to either pay a yearly subscription to the service or pay for sacks and inform the collection authority when the service is required. Analyses of the LA websites suggest that the opt-in services are relatively new and again, most of the LAs are moving towards this method of collection for green waste.

Table 1.2 – Waste Collection methods used by Welsh Local Authorities as of October 2014.

Local Authority	Type of Collection	Residual Collection	Food Waste	Green Waste
Isle of Anglesey CC	Kerbside Sort	Fortnightly	Weekly	Fortnightly
Blaenau Gwent CBC	2 stream - Paper Separate	Fortnightly	Weekly	Opt in - Payment
Bridgend CBC	Kerbside Sort	Fortnightly	Weekly	-
Caerphilly CBC	Commingled	Fortnightly	Weekly	Weekly
Cardiff CC	Commingled	Fortnightly	Weekly	Fortnightly
Carmarthenshire CC	Commingled - No Glass	Fortnightly	Weekly	Opt in - Payment
Ceredigion CC	Commingled - No Glass	Fortnightly	Weekly	Opt in
Conwy CBC	Kerbside Sort	Fortnightly	Weekly	Fortnightly
Denbighshire CC	Commingled	Fortnightly	Weekly	Fortnightly
Flintshire CC	Kerbside Sort	Fortnightly	Weekly	Fortnightly
Gwynedd Council	Kerbside Sort	3 weekly	Weekly	Fortnightly
Merthyr Tydfil CBC	Commingled	Fortnightly	Weekly	Weekly
Monmouthshire CC	2 stream - Paper Separate	Fortnightly	Weekly	Opt in - Payment
Neath Port Talbot CBC	Kerbside Sort	Fortnightly	Weekly	Opt in - Payment
Newport City Council	Kerbside Sort	Fortnightly	Weekly	Fortnightly
Pembrokeshire CC	2 stream - Glass separate	Fortnightly	Weekly	Opt in - Payment
Powys CC	Kerbside Sort	Fortnightly	Weekly	Opt in - Payment
Rhondda Cynon Taff CBC	Commingled	Fortnightly	Weekly	Weekly
City and County of Swansea	2 stream - Plastic Separate (fortnightly)	Fortnightly	Weekly	Fortnightly
Torfaen CBC	Commingled - Card separate	Fortnightly	Weekly	Summer only - Fortnightly
Vale of Glamorgan Council	Commingled	Fortnightly	Weekly	Fortnightly
Wrexham CBC	2 stream - Paper Separate	Fortnightly	Weekly	Fortnightly

1.4 Decision Making in the Context of Waste Management

LAs are under considerable pressure from Government to achieve the best possible recycling rates, given the legislation that is passed at a European level and these challenges that they face are introduced in this chapter. With so many alternatives for residual, biodegradable waste and recyclate collection available for a LA, and much conjecture about the best method to use, the decision making process becomes vitally important. There are also numerous decision making methods to validate this selection, that selecting the right approach is another process altogether.

Whilst deciding on the method of collection, legislative, economic and environmental matters must all be considered at the same time, with uncertainties about the direction that must be followed, as highlighted by the consultation in Wales outlined previously (Welsh Government 2014). This creates a high pressure situation for LAs that must renew their fleet, hire new staff or generally update their service as once the decision is made, a change in the near future can prove to be very costly. They require a robust and proven methodology to aid with this process and to document why the decisions that are made at a given point in time, with the information available, are made.

The statistics provided by StatsWales, the governmental statistics department for Wales, outline that there have been examples of wrong decisions made in the waste management sector. These include Flintshire County Council (CC) who from 2006/07 with a recycling/composting rates of 33.4%, experienced a slight drop in 2007/08 to 32.8%. In Bridgend CBC these rates in 2008/09 were 34.6% but dropped fairly significantly to 31.1% in 2009/10, however both authorities have since increased their recycling and composting rates (StatsWales 2014b). The reasons for these drops may be linked to a service that needed changing, or disengaged householders that did not take part in the scheme. Either way, if there is no documentable evidence as to why the rates dropped for a year, how can an effective change be outlined without an effective decision making method?

Moreover, Powys County Council (CC) experienced sustained regular drops in levels of recycling and composting from 2007/08 where they achieved 41.2% to 2010/11 where they only achieved 36.6%. They have since managed to achieve 41.9% by 2011/12, which is about the same rates they were achieving four years previously. Since Powys is the largest council in Wales by land mass, with a mixture of small towns and vast rural areas, stimulation and communication is difficult to achieve, leading to obvious inconsistencies. Refocussing and targeting of specific areas have increased the recycling rate.

1.5 Aims and Objectives

The following bullet points outline the aims of this study, followed by a short description of the objectives for each.

- ***To understand the decision making process and explore the complexity of the decision making process in waste management it can be understood.***

  This is done through the literature review, so that logical step by step method can be defined.

- ***To clarify the Drivers and Barriers and outline the main criteria for Local Authorities.***

  This is clarified by understanding what areas of importance the LAs focus on to undertake their decision making process. This is understood through consultation with Welsh LAs, Welsh Government and waste management operatives. It is possible to understand how their resources are deployed and how that impacts upon their decision making path. This will be visualised using a 'decision making tree'.

- ***Develop a tool that implements a decision making methodology, to aid the multifaceted process, given the legislative, economic, environmental and social pressures, in a kerbside collection.***

  To achieve this, a proven and recognised methodology underpinning its use must be used. Developing on an existing methodology and adapting it for use in the waste management sector, a novel approach to decision making in waste management will be put forward. It will give the user robust and documentable decision support, allowing the decision making process to be followed easily.

- ***To create scenarios for classification of authorities and comparison against a case study authority, to judge whether the decision made was correct.***

  Using the Drivers and Barriers, scenarios will be created to understand the effect these have on the decision making process. To achieve the overall aim, this will be applied to a case study authority and compared to the scenarios created. Their decision will be broken down to understand where their main areas of focus are and what size of impact they have. Their decision will also be compared with the method they used previously to undertake the decision making process, for the best method of municipal solid waste collection.

1.6 Structure of the Thesis

Chapter 1 introduces the subject area, Chapter 2 contains the literature review outlining decision making in general, followed by how this is currently implemented in the Waste Management sector. Chapter 3 will identify the drivers and barriers that face local authorities and introduce the case study authority.

Chapter 4 explains the methodology that was chosen, for its suitability and why this was the case. It also takes the reader through the development process of the proposed tool for decision making in waste management. Chapter 5 contains a detailed discussion of the results, examines different scenarios and the impact these have on the decision making process. By examining the effect of differing weightings of criteria, what impact this has. Chapter 6 concludes the thesis and proposes areas for future research, followed by a reference section.

2. Review of Decision Making and Decision Support Tools

2.1. Introduction

At a basic level, decision making takes place in everyday activities, as well as in industry. The process itself can be defined as choosing between alternatives based on the preferences, morals and values of the decision maker, whilst identifying the option that either has the highest probability of success or achieves objectives set (Harris 1980; Beach 1996). Whether these are subconscious or prescribed as such, everything involves decision making. The key to decision making is considering values and goals of stakeholders and experts on the matter. This means decision making can garner a subjective or objective decision, dependant on the basis of the information used (Sauter 1997).

If this process is formalised, then there is a prescribed method that must be adhered to, if it is to be considered as a disciplined decision making (DM) process. The route map for such a process is shown in Figure 2.1 and flows from step 1 through to the end. However, as and when new information is unveiled, the process may revert back to any previous step before carrying on (Baker et al., 2001).

Most importantly, the problem to be solved must be well defined and if not, then the whole process will be inaccurate. All stakeholders must be directly involved in this part of the process so that their direction of focus can be included. The stakeholders and the decision maker(s) agree on one clearly distinct written statement that includes the initial conditions.

For step two, the requirements that must be achieved are indicated. These are elements that *must* be achieved to accomplish the goal, regardless of any other mitigating factors. If the decision making process is carried out by a group, then they cannot be viewed as desirable by some, they must be regarded as necessities by all. The third step covers any goals, which can be based on opinion, which solving the problem should accomplish. These positively expressed elements are surplus to what must be and are not necessities in themselves and should benefit the outcome of any decision made.

Once all criteria that must be achieved are targeted and any goals outlined, the alternatives that are solutions to the problem, and transform the initial to the desired conditions, must be addressed. These are the elements that are going to be carried out, even if this is something as small as giving an answer as yes or no. Equally, this can be something with a larger impact on the stakeholders/decision maker(s) such as investment in new construction, vehicles, employees etc. These alternatives must answer to the requirements and ideally fulfil the goals established in step three.

The evaluation criteria must be defined for every requirement and goal across the board and followed by the individual or the group. This will provide coherent decision making so that the process can be followed by others who may wish to be informed at a later stage. The evaluation criteria are used to measure and compare the performance of each alternative in relation to the requirements and must therefore not depend on one another (Baker et al. 2001).

A methodology can then be selected that best achieves the purpose of the process. Factors that must be considered include whether the data at hand is qualitative or quantitative, depending on the type of criterion, the comparison can either be subjective or objective. Thus the nominated tool may have to deal with qualitative, quantitative or a mixture of the two types of data, so that the procedure can be selected appropriately. This also means that the selected methodology may be very simple or complex. If there are few elements to consider, there is no need to over complicate matters by passing information through many stages (Fülöp 2005). Equally, if there are many elements to consider a more thorough investigation must be carried out, otherwise certain elements may not be considered that should have done and may have a very large impact on the final decision made. If there are many requirements, goals and alternatives, the complexity of the problem is high, as many comparisons are needed to undertake the decision making process and it is almost impossible for a rational decision to be made without some form of support. The methodology must be as simple as possible, but not so much so that it affects the accuracy of the process and the outcome of the analysis, as this will minimise errors occurring if the process is particularly complicated (Hall et al. 2007).

In most cases a Decision Support Tool (DST) is required to aid in this process and can be applied to evaluate the alternatives against the criteria set, to find the relative perfomance of each alternative. The application of the DST and its corresponding methodology will allow an answer to be given in the selection of one of the alternatives as laid out in step four. If it is thought by the decision maker(s) that the selected alternative is not the most suitable, the process should be repeated. This could be from the very beginning to ensure the goal is the correct one; it may be the requirements and the goals have been jumbled and therefore need re-evaluation as to which should be which; or there may be alternatives which were not considered and subsequently should now be included.

Once the comparisons are made, then the preferred alternative is offered to the decision maker(s) and any stakeholders to review and ensure that it meets all the requirements and achieves the goals to an agreeable point.

The steps, as outlined above, must be adequately performed, with comparisons, decisions and agreements/disagreements documented, to ensure all round satisfaction. If at any point new information is unveiled, the decision maker(s) can go back to any previous point and carry out again the steps in sequence.

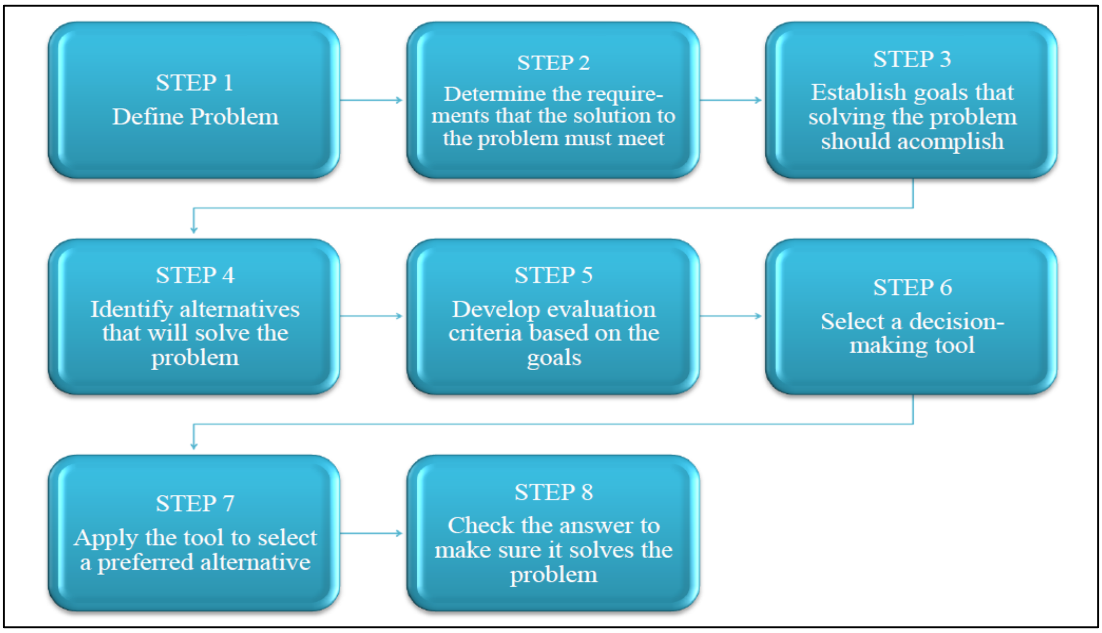


Figure 2.1 – The 'route map' of the Decision Making Process (Baker et al. 2001)

2.2. Decision Making Methods

There is a wide variety of decision making methods available and depending on the complexity of the problem, along with the knowledge base of the decision maker(s), a selection of the appropriate methodology can be made.

At a basic level, good decisions come from a good decision making process (Buchanan et al. 1998). It is argued by Buchanan et al., that the objective and subjective should be separated and move to a more objective approach. It is of the author's opinion that this is not the case and while they must be separated, the key is to use both and allow some subjectivity. Whether the personal choices are requirements or goals is up to the decision maker (DM); however the alternatives are generally objectively defined. A good question is how one obtains the subjective criteria?

The work of Keeney and Raiffa (1976) is widely accepted as the formative work in decision making. Their work which laid out the foundations of multi attribute decision making, is referenced by many in outlining and debating methodologies for decision making. The methods outlined in this review, are founded on the three basic principles of multi attribute problems that Keeney and Raiffa (1976) outlined:

- Performance matrix – rows and columns that represent the interaction of criteria and alternatives in a problem that must be addressed

- Procedure – to determine whether the criteria are independent of each other

- Mathematical computation to show the decision makers valuation

How many criteria and alternatives are to be considered and the type of information that each criteria requires, will affect the decision making process to be selected, as it may have to deal with quantitative and qualitative data. Quantitative data concerns those which can be measured numerically, be it an absolute mass, percentage or distance. Qualitative data pertains to the quality of an entity or subjective views of the decision maker(s). In the example, the quantitative data narrowed down the options but eventually subjectivity was the deciding factor.

2.3. Most Common methodologies

2.3.1 Single vs Multi Criteria Methods

If there is one measure that is under scrutiny, this judgement can be highlighted as a single criteria decision. A direct comparison of the alternatives, with an easily defined best option can yield the required outcome If, for example, the selected criterion was the cost of a product/service/item, then the implicit decision is made by determining the best value alternative (Zimmermann 1990).

Where there is a requirement to consider many elements, the decision making process falls under a suite of methods named Multi-Criteria Decision Analysis (MCDA). For example, a group of decision makers that are contemplating producing a new product may first consider all the costs of producing, advertising and shipment of this new product. With only one attribute to consider, a direct comparison can be made for the decision making process. However, legislation may dictate that they must also consider the environmental impacts of this product. Both attributes must then be considered simultaneously by a MCDA model, using a common metric. This can extend to many more criteria included in an analysis, leading to a systematic review requirement of the goal (Hahn et al. 2012).

MCDA has two sub sections that can be classified as Multi-Objective Decision Making (MODM), which considers large, infinite or an uncountable number of alternatives; or Multi-Attribute Decision Making (MADM) allowing for small, finite or countable alternatives in a decision making procedure (Hopfe et al. 2013). In a waste management context, MODM could be applicable. There are innumerable ways to count collection scenarios with the possibility of weekly, fortnightly, three weekly and monthly collections alongside residual, recycling, food, green and bulky waste collections with the ability to apply all possible permutations. On the other hand, using certain collection possibilities can be ruled out or minimised, leading to the use of MADM. In reality, the two are almost indistinguishable as invariably through analysis, certain alternatives are rejected through the various stages of the decision making route map. Some of the options are not feasible, legislatively unusable, or socially unacceptable.

A feature of MCDA is the visual representation of the decisions that are being undertaken, involving the generation of a matrix as outlined in Equation 2.1. Each row represents the alternatives defined in the DM process whilst the columns constitute the criteria that the alternatives must perform against. In any MCDA problem, if there are *m* alternatives and *n* criteria, let $A_1, \dots, A_m$ represent the alternatives and $C_1, \dots, C_n$ represent the criteria. The weighting of each criterion, $w_1, \dots, w_n$, defines the importance of the criteria that is to be applied to the weighting of each alternative, represented as $x_1, \dots, x_m$. The weights of the criteria are assumed to be positive and are normally subjective, however it is possible for the weightings to be assigned relating to quantitative data (Fülöp 2005). The interactions of the criteria and alternatives populate the matrix terms of the decisions made, in the form:

$$\begin{array}{cc} & \\ & \\ \boldsymbol{x_1} & \boldsymbol{A_1} \\ \vdots & \vdots \\ \vdots & \vdots \\ \boldsymbol{x_m} & \boldsymbol{A_m} \end{array} \begin{array}{c} \begin{array}{cccc} \boldsymbol{w_1} & \dots & \dots & \boldsymbol{w_n} \\ \boldsymbol{C_1} & \dots & \dots & \boldsymbol{C_n} \end{array} \\ \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1n} \\ z_{21} & z_{22} & & \vdots \\ \vdots & & \ddots & \vdots \\ z_{m1} & \dots & \dots & z_{mn} \end{bmatrix} \end{array} \qquad \textbf{(2.1)}$$

Dependent upon the methodology applied, this matrix and its composition may vary. It may be the case that criteria are compared to each other first but the method remains the same. The basic concept that a solution alternative will be subjected to performance evaluation with respect to each criterion holds true through all methodologies. The weightings can be qualitative or quantitative and represent the decision maker's opinion or a synthesis of a group's decision or directly relate to data with a higher ranking.

There must be justification alongside the decision, as to why its benefits are more important and the disadvantages are less consequential than others, which are offered by using the methodologies as outlined in section 2.3.2. Where there is need for computational assistance, decision support systems are required and will be explored once some of the available methodologies are outlined. These will start from the relatively simple and move on to the more complex, which usually require a Decision Support System (DSS) or tool (DST).

2.3.2 Elementary methods

These methods are relatively uncomplicated and usually apply when a single decision maker is required, with few alternatives and criteria to consider. Elementary methods do not generally require computational aid as the criteria under scrutiny usually do not require weightings and can be heavily influenced by individual's views (Linkov et al. 2004). These methods are:

Voting – A very common method which is used to decide many things from government, to decisions at a meeting for a company or the decision for what to do for a group of friends over the weekend. This is a purely opinionated view to influence the outcome of the decision. There must be at least two possible alternatives for a vote to take place and the 'winning' outcome, is the one that receives the majority.

Flow Chart – Using a flow chart is a very useful method for laying out the steps that must be taken when considering a project. It can involve yes/no answers that lead the user to the ultimate destination, a solution alternative. This method is useful when there are step by step objectives that must be achieved and is clearest when few alternatives are available.

Pros and Cons Analysis – requires predominantly qualitative analysis and compares the good elements with the bad for the alternatives given in relation to discriminating criteria. The alternative with the strongest pros and the weakest cons is the preferred option and must include documentation justifying these choices. A Pros and Cons Analysis can be based on quantitative data, e.g. the cost of an object, but is ultimately qualitative, as the decision is made without mathematical input (Baker et al. 2001).

Maximax and Maximin– Put simply, these comparable methods find the 'best of the best' solution alternatives and the 'best of the worst', respectively. Maximax analysis will cause the decision maker to list the alternatives in terms of their respective outcomes. The score of its strongest performing criterion that is highest is the preferred alternative thereby maximising the maximum standard. Alternatively, Maximin looks at the weakest performing criteria of the solution alternatives that could happen and chooses the best performing of these, thereby maximising the minimum standard (Ossadnik et al. 2012). Examples of how this has been implemented in the assessment of price volatility of energy prices and planning for climate change are outlined by Inda et al. (2014) and Green and Weatherhead (2014).

2.3.3 Non Elementary Methods

Cost Benefit Analysis is a very useful method to carry out the analysis of financial or organisational benefits and their comparison with disadvantages of a project or system. It is a systematic quantitative analysis for time, labour and any other factor where a financial value can be placed on alternatives, to verify whether they satisfy a certain goal or criteria (David et al. 2013). In essence, this is a comparison of the monetary benefit against the monetary cost of the alternatives. Adjustments are made for the time value of money using net present value. Future cash flows are taken into consideration where money today may have a different purchasing power in comparison to a decade or more later (Cellini and Kee 2010). Cost Benefit Analysis has been used in areas such as health in the evaluation of using emergency contraception (Gross et al. 2014) and breast cancer. Also in the environmental sector for water and waste management (Jayasooriya and Ng 2014; Bhatnagar et al. 2014; Sanchez Reinoso et al. 2014; Manni and Runhaar 2014) and education (Sword 2013).

Pareto Optimality Analysis – was introduced by Francis Ysidro and generalised by Vilfredo Pareto and originally applied to economics and business situations (Coello Coello et al. 2002). It is a vector optimization based on dominance. If vectors are assigned to comparative candidate solutions, represented by u and v, then u is Pareto-dominate if $f(u) \leq f(v)$, in a minimisation context. For this to hold true and be considered Pareto optimal, there must not exist any solution that can dominate it, thereby adhering to the ideal of a best solution gives the best value for each criterion without affecting others (Ngatchou et al. 2005).

It outlines the allocation of resources in the most efficient manner, where one element's situation cannot be improved without hindering another. It has been adapted to be used in many situations because invariably where choices must be made, the improvement of one factor impacts upon another. For example the improvement of an environmental factor will generally cost more through investment for infrastructure, thereby impacting on the economic side of a project. This set of solutions results in a trade-off curve, known as a Pareto frontier that visualises for the decision maker the 'ideal solution across a spectrum of weight combinations' (Lu and Anderson-Cook 2014). Figure 2.2 is an example of this in sheet metal forming where the frontier is dependent on the strain.

Pareto optimisation is used in a wide variety of sectors however the documentation tends to be specified in the engineering and computer science areas. Examples of where it has been used include its use as a comparison tool for gaming interfaces (Vorobyov et al. 2012), the calibration of a flow model compared to real life situations in gated culverts (Wilsnack et al. 2012) and optimisation of the sheet metal forming process (Wei and Yuying 2008).

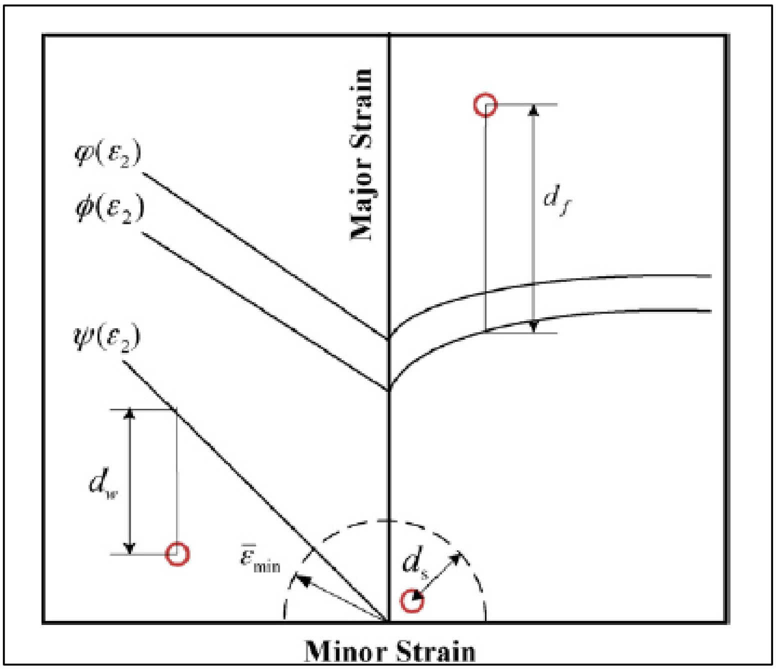


Figure 2.2 - Example of an optimization curve for sheet metal forming (Wei and Yuying 2008)

2.4. More Complex Methods

The two main areas for MCDA are called Multi Attribute Utility Theory (MAUT) and Outranking Methods (OM). Both methods work in similar way by suggesting the best alternative given the criteria and the subjective or objective weightings applied. However MAUT works under the understanding that a gain in one area must result in a loss in anther due to the aggregation in the function that leads to compensation (Fülöp 2005). OM state that alternative A_i outranks A_j, if the main constituent of A_i achieves at least as good a result as A_j, whilst the worst performance scenario is still acceptable (Roy 1990). These will be explored in further detail.

2.4.1 Multi Attribute Utility Theory

Multi-Attribute Utility Theory (MAUT) integrates qualitative and quantitative data effectively whilst giving a structured approach to solving the trade-offs among multiple objectives (Kijak and Moy 2004). It takes into consideration a DMs preferences in the form of a utility function that is defined over a set of attributes (Pohekar and Ramachandran 2004), to give utility unit scales to allow direct comparisons of diverse attributes. The solution alternatives are then ranked in order of preference, generally on a dimensionless scale from nought to one (0-1), after the application of the method chosen. The utility function takes on a vital role in the conversion of the performance values to signify those that earn a greater performance, having a higher utility value e.g. where cost minimisation is a criterion under examination, the lower a cost of an alternative, will result in a higher utility value. In some cases, the values obtained can be normalised against the best performing criteria to give an straight forward method of comparison. This is important, as the result of any methodology provides the best performing alternative as a suggestion, not a definitive answer.

Weighted Sum and Weighted Product Method – The Weighted Sum Method (WSM) is the simplest form of MAUT. The first principles required are that the performance of each alternative in relation to each criteria can be evaluated and are measurable, giving the z_{mn} values as outlined in Equation 2.1. Secondly, they must have the same measurable means and finally, assuming that a better performance means a higher value number, the alternative with the highest cumulative value is the most preferred option (Triantaphyllou and Baig 2005). The most preferred alternative calculated is A_{WSM} in Equation 2.2:

$$\boldsymbol{A_{WSM} = max \sum_{j=1}^{n} z_{ij} w_j \,, \; for \; i = 1, 2, \dots, m} \qquad \textbf{(2.2)}$$

For example, where the implementation cost of an environmental project is being compared to the running costs, WSM could be used. If the Carbon Dioxide (CO_2) output were to also be considered, this has a different means of evaluation and therefore WSM could not be used. Instead, the Weighted Product Model (WPM) could. WPM uses ratios between alternatives, for each criterion, to create a dimensionless analysis owing to the elimination of any units of measure. Each ratio is then raised to the power of the criterion's corresponding weighting, leading to the equation (Miller and Starr 1969):

$$\boldsymbol{R}\left(\frac{\boldsymbol{A_K}}{\boldsymbol{A_L}}\right) = \prod_{\boldsymbol{j=1}}^{\boldsymbol{n}} \left(\frac{\boldsymbol{z_{K_j}}}{\boldsymbol{z_{L_j}}}\right)^{\boldsymbol{w_j}} \qquad \textbf{(2.3)}$$

Where $R\left(\frac{A_K}{A_L}\right)$ represents the ratio between the two alternatives and if $R\left(\frac{A_K}{A_L}\right) \geq 1$ then A_k is preferred, assuming maximisation is the goal. The alternative that performs better than, or at least equal to all others in all criteria, is the most desirable outcome for the decision maker(s).

This methodology has been applied to fewer areas than others in MAUT as it is mostly used in single dimensional problems that are characterised by two criteria that have the same unit of comparison (Triantaphyllou 2000).

Simple Multi Attribute Rating Technique (SMART) – Simple Multi-Attribute Rating Technique (SMART) is the next simplest form of MAUT, assigning a ranking value, x_i, for each alternative, A_i. This is obtained by multiplying the weighting assigned, w_i, by the performance of each alternative, a_{ij}, and dividing this value by the summation of the weightings as represented by (adapted from Fülöp (2005)):

$$x_i = \sum_{i=1}^{n} w_i a_{ij} \Big/ \sum_{i=1}^{n} w_i\,, \quad i = 1,2,\ldots,n \qquad \textbf{(2.4)}$$

The advantage of SMART is that all variances in criteria values are taken into account, thanks to the assignment of numerical values to represent differences such as preference and incomparability. However, to not compromise the efficiency of this method, a limited number of criteria are suggested to be no more than eight (Edwards and Barron 1994). Edwards and Barron improved on the basic application of SMART to create SMARTS (SMART using Swing), which was further improved to create SMARTER (SMART **E**xploiting **R**anks) (Barron and Barrett 1996). SMARTS considers the amplitude of the utility values of the alternatives, thereby adding the

Swing element to SMART, and SMARTER adds a justification of rank weights to the SMARTS process. This method's simplicity limits the extent to which it can be used. However, SMART and its derivatives have been used in decision making in sustainable energy as a comparable method by Wang et al. (Wang et al. 2009) through to selecting suppliers in the construction industry (Schramm and Morais 2012).

2.4.2 The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) was created by Saaty (1980) and has a plethora of uses for the decision support method. It is used by the military for analysis through to the planning of transportation systems and selecting schools for children (Saaty 1980). A valuable benefit of this methodology is that AHP can use qualitative and quantitative information together to assess a problem.

AHP uses pairwise comparison to evaluate the items in pairs and judge which alternative is preferred, or has a more beneficial outcome should it be used in lieu of the other. It uses a hierarchical tree structure where each element in a higher layer is used to compare those elements in the layer immediately below with respect to it. Each judgement is carried out using a scale from 1 to 9, shown in Table 2.3.

Table 2.3 - Importance Ratings and their Definitions adapted from Saaty (1980)

Importance Rating	Definition	Explanation
1	Equal Importance	Two factors have equal importance
3	Somewhat more Important	Experience and judgement weakly favour one over the other
5	Much more Important	Experience and judgement strongly favour one over the other
7	Very much more Important	One factor is either demonstrably or very strongly more important than the other
9	Absolutely more important	The evidence favouring one over the other is unequivocal
2,4,6,8	Intermediate values	When compromise is needed

Firstly, an overall goal must be outlined followed by the criteria, C_n, and solution alternatives, A_n, following a similar trend for all MAUT methods. A matrix, A, for the comparison of each criterion, in relation to the goal or the associated criterion in the level above, must be undertaken. The easiest way to visualise this is to set out a hierarchical structure such as Figure 2.3. The four lines that join Criterion 2 to Subcriteria 2a, 2b, 2c and 2d represent the matrix that must be created for the comparison of the four subcriteria in relation to criterion 2. The same applies for the four lines emanating from the four solution alternatives to all six of the subcriteria. One compares criterion C_i with C_j using the scale shown in Table 2.3, and let z_{nn} denote this comparison of criteria to give the matrix:

$$\begin{array}{c c} & \begin{array}{cccc} \boldsymbol{C_1} & \boldsymbol{C_2} & \cdots & \boldsymbol{C_n} \end{array} \\ \begin{array}{c} \boldsymbol{C_1} \\ \boldsymbol{C_2} \\ \vdots \\ \boldsymbol{C_n} \end{array} & \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1n} \\ z_{21} & z_{22} & & z_{2n} \\ \vdots & & \ddots & \vdots \\ z_{n1} & z_{n2} & \cdots & z_{nn} \end{bmatrix} \end{array} \qquad \textbf{(2.5)}$$

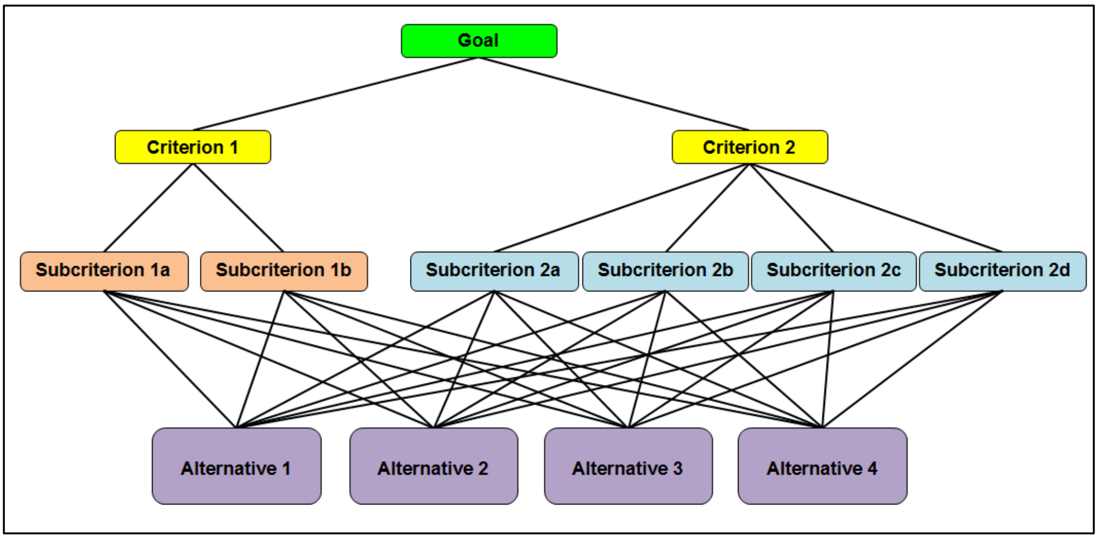


Figure 2.3 - Hierarchical Structure for AHP

Comparisons of any pair of criteria or alternatives will be subjected to a reversal comparison as well i.e. z_{12} may have been given a value of 3, so what becomes of z_{21}? To avoid inconsistency through human error, it is deemed that $z_{nm} = {}^{1}/_{z_{mn}}$, resulting in the bottom half of the matrix comprising of the reciprocals of the decisions made. So, if $z_{12} = 3$ then $z_{21} = {}^{1}/_{3}$.

When an element is compared with itself, it is identical and therefore of equal importance giving $c_{ii} = 1$. Thus resulting in the main diagonal of the matrix consisting of 1's, similar to the identity matrix, and the reciprocal of each judgement represented in the lower half of the matrix (Saaty and Ozdemir 2003) giving:

$$\begin{array}{cc} & \begin{array}{cccc} \boldsymbol{C_1} & \boldsymbol{C_2} & \cdots & \boldsymbol{C_n} \end{array} \\ \begin{array}{c} \boldsymbol{C_1} \\ \boldsymbol{C_2} \\ \vdots \\ \boldsymbol{C_n} \end{array} & \begin{bmatrix} \boldsymbol{1} & \boldsymbol{c_{12}} & \cdots & \boldsymbol{c_{1n}} \\ \boldsymbol{1/c_{12}} & \boldsymbol{1} & & \boldsymbol{c_{2n}} \\ \vdots & & \ddots & \vdots \\ \boldsymbol{1/c_{1n}} & \boldsymbol{1/c_{2n}} & \cdots & \boldsymbol{1} \end{bmatrix} \end{array} \qquad \textbf{(2.6)}$$

Once the matrix is created, a vector of priorities (weightings) may be determined. Allowing for inconsistencies in human decision making, mathematically speaking, the principal eigenvector is calculated for this task (Saaty 2003). Whilst it is possible to calculate the eigenvector accurately and easily for a 2*x*2 matrix, it can be time consuming and when computing the eigenvector for a 7*x*7 matrix say, this becomes unfeasibly laborious. Instead, there are alternative methods that can give an estimate for the vector of priorities. The simplest would be to sum the elements in each row and normalising by dividing each sum by the total of all sums. When the weightings are analogised by this crude method, the weightings of the priority vector are close, but not accurate enough (Saaty 1980).

For this reason, an acceptable method includes calculating the geometric mean. Multiplying the elements (of number *n*) in each row and taking the *n*th route, and normalising by dividing the geometric means by their total, gives an acceptably accurate approximation combined with a relatively uncomplicated calculation method. For most cases, when the result is taken to two decimal points, it is identical to the exact vector (Saaty 1980). When this calculation has to be carried out many times, this method becomes the most logical.

As decision making in humans can be naturally inconsistent, a method of checking for an element of consistency is needed. Where a matrix can be considered consistent if it is reciprocal in nature, a near consistent matrix is one where there is only a small variance (Saaty 2003). As humans are not robots capable of processing data perfectly, this is not detrimental and must be accepted as a variable to deal with.

Alonso and Lamata (2006) and Saaty (2002) outline the method and reason why λ_{max}, the principal eigenvalue calculated by finding the geometric mean for simplicity, is important for calculating the consistency of the matrix itself. Simply put, for an *n x n* matrix, the closer that λ_{max} is to *n*, the more 'perfect' the judgements are. Small changes in λ_{max}, and its deviation from *n*, show the uniformity of decisions made and the consistency index (CI) can be evaluated by:

$$\boldsymbol{CI = \frac{\lambda_{max} - n}{n-1}} \qquad \textbf{(2.7)}$$

The CI is then used to define a consistency ratio (CR):

$$\boldsymbol{CR = \frac{CI}{RI}} \qquad \textbf{(2.8)}$$

The random index (RI) is defined as the CI of randomly generated reciprocal matrices, with scale 1 to 9 and reciprocals forced (Saaty 1980). For the value of RI to be used with this method, an average was produced in a combination of studies for square matrices of up to order n = 10, of randomly generated reciprocal matrices (Saaty 1980), the results of which are shown in Table 2.4.

Table 2.4 - Average Random Index for a square matrix of order *n*

Size of Matrix	Random Consistency		Size of Matrix	Random Consistency
1	0		6	1.24
2	0		7	1.32
3	0.58		8	1.41
4	0.90		9	1.45
5	1.12		10	1.49

Although it is widely assumed that a CR of 0.1 is generally considered 'acceptable', this was a guideline set when AHP was introduced. Dodd et al. (1993) reassert that it was intended to be a tentative measure, especially when the judgements are applied to many layers of decision making. It is down to the DM as to what value should be deemed acceptable. If any consistency ratios come out above this value, they would have to reassess the comparisons and make appropriate changes to fall in line with the guideline value of CR. Needless to say, the reasoning for setting a particular limit for the CR and any revisions must be well documented for clarity.

The literature available shows AHP has been used in a wide variety of applications, but is heavily found in the environmental (Stefanidis and Stathis 2013; Tong et al. 2012) and energy planning sectors (Tan and Promentilla 2012; Ren et al. 2013).

2.4.3 Outranking Methods

Outranking methods (OM) use the same type of information and data as MAUT in respect to the use of criteria and alternatives to solve a problem facing a decision maker. In principal, these methodologies also use the comparative weightings, z_{ij}, and weightings, w_i.

***EL**imination **E**t **C**hoix **T**raduisant la **RE**alité (Elimination and Choice Expressing Reality* – ELECTRE) is the most widely used method of outranking and was formally introduced by Roy (1968). Similar to MAUT, OMs build a preference amongst alternatives or criteria, to give a suggested ‘best’ approach (Bouyssou 2001). There are many versions of the ELECTRE method which all operate in slightly different ways (Figueira et al. 2005). However, they are fundamentally underpinned by the same principle and they work using thresholds and outranking concepts.

Assume a set of criteria, g_j, for $j = 1, 2, \ldots r$, and a set of solution alternatives, A. Starting with the following basic assumptions and focusing on two alternatives (a, b) as elements of A, where:

a is preferred to *b* - $a\boldsymbol{P}b$ - $C(a) > C(b)$ **(2.9)**

a is indifferent to *b* - $a\boldsymbol{I}b$ - $C(a) = C(b)$ **(2.10)**

a cannot be compared to *b* - $a\boldsymbol{J}b$ **(2.11)**

However, there is more to decision making than strict mathematical ideas, such as '*a* is definitely preferred to *b*'. For example if two projects are being compared to each other and one costs £100 million and the other costs £101 million, is this difference enough to say that one project is definitely preferred to the other? To account for this, an indifference threshold, q, is introduced. The value of q is subjective to the decision maker and affects preferences as follows (Buchanan et al. 1998):

$a\boldsymbol{P}b$ - $C(a) > C(b) + q$ **(2.12)**

For a to be preferred, it must be more than the value of b plus the subjective indifference value.

$a\boldsymbol{I}b$ - $|C(a) – C(b)| \leq q$ **(2.13)**

The difference between a and b must be less than the value of q, for a and b to be indifferent

$a\boldsymbol{J}b$ - Unaffected **(2.14)**

The indifference threshold helps bridge the gap for the decision maker, to account for the imperfect nature of human evaluations. Therefore, there is also reason to differentiate between when a decision maker hesitates between a strict preference and indifference and is represented by p (Roy 1991). This zone measures weak preference, $\boldsymbol{Q}$, and affects the statements thus:

$a\boldsymbol{P}b$ - a is **strongly** preferred to b - $C(a)\text{-}C(b) > q$ **(2.15)**

$a\boldsymbol{Q}b$ - a is **weakly** preferred to b - $q < C(a)\text{-}C(b) \leq p$ **(2.16)**

$a\boldsymbol{I}b$ - a is **indifferent** to b and vice versa - $|C(a)\text{-}C(b)| \leq q$ **(2.17)**

To best reflect decision making environments there is good reason for non-zero values of p and q, as it represents the human way of thinking. Some things are preferred only a little compared to others. When p and q have been set, ELECTRE creates the outranking relation, $\boldsymbol{S}$, where $a\boldsymbol{S}_jb$ means ‘a is at least as good as b in relation to the j^{th} criterion’

The final check to be undertaken is that of concordance and discordance. For the j^{th} criterion, it is in concordance if, and only if $a\boldsymbol{S}b$ is $a\boldsymbol{S}_jb$ therefore:

$C_j(a) \geq C_j(b) - q_j$ **(2.18)**

If *a* is less than *b* by up to the value of *q*, it does not contravene the assertion and therefore is considered to be in concordance. A criterion is considered to be in discordance with the assertion ***aSb*** if, and only if, ***bP**ja*** and therefore:

$C_j(b) \geq C_j(a) + p_j$ **(2.19)**

Thus if *b* is strictly more preferable than *a* by at least a value of *p*, then it is in discordance with the assertion ***aSb***. Once this has been carried out for all criteria with respect to the alternatives, it essentially shows how many of the *j* criteria where *a* is preferred to *b*. A concordance index, ***C****(a,b)*, measures this assertion and is defined as:

$$\boldsymbol{C(a,b) = \frac{1^r}{k_{j=1}} \sum_{j \in C(aSb)} k_j . c_j(a,b)} \qquad \textbf{(2.20)}$$

Where *k* is the subjectively set weighting of each criteria and ***C****(a, b)* lies between 1 and 0 inclusive (Roy 1990). The concordance index will be 1 when the evaluation of *a*+*q* is more than *b* and 0 when *a+p* is less than *b*. For any that do not satisfy these two evaluations, then the index is defined as θ:

$$\boldsymbol{\theta = \frac{p_j + g_j(a) - g_j(b)}{p_j - q_j}} \qquad \textbf{(2.21)}$$

The various alternatives are considered in a pairwise manner with respect to each criterion and their concordance indices are placed in a matrix.

The major point of conjecture with this method is the allocation of the weightings for the criteria. They are applied by the stakeholder using their perception, which means that they can skew the outcome accordingly.

ELECTRE methods have been used in many fields for decision making and most recently in areas such as tourism (Chanvarasuth and Boongasame 2014; Mailly et al. 2014), architecture (Fontenelle and Bastos 2014) and renewable and sustainable energy (Jun et al. 2014; Sánchez-Lozano et al. 2014)

The **P**reference **R**anking **O**rganization **METH**od for **E**nrichment of **E**valuations (PROMETHEE) was developed and formally introduced by Brans in 1982 at

L'Engéniérie de la Décision – Elaboration d'instruments d'Aide à la Décision (Brans and Mareschal 2005). It is a variation of the ELECTRE method and follows a similar pattern to all OM but uses pairwise comparisons for analysis. When two alternatives in respect to criteria are compared to each other, there is a preference of one over the other, indifference or incomparability (P, I and R respectively). Secondly, weightings, w_j, must be assigned to each criterion to show importance, but can also be normed so that:

$$\sum_{j=1}^{k} w_j = 1 \qquad \textbf{(2.22)}$$

A ranking preference for each alternative over another, with respect to each criterion must be made via pairwise comparison, with deviations assigned as a value between 0 and 1. The larger the preference, the closer the value will be to 1 and the more negligible the difference, the closer this value will be to 0 (Brans and Vincke 1985). Therefore, if $g_j(a)$ and $g_j(b)$ represents the values assigned for alternatives a and b with respect to criterion g_j then:

$$d_j(a,b) = g_j(a) - g_j(b) \qquad \textbf{(2.23)}$$

where $d_j(a, b)$ is the deviation between the two alternatives for each criterion. This leads on to finding the function for preference of a over b using:

$$P_j(a,b) = F_j\left[d_j(a,b)\right] \qquad \textbf{(2.24)}$$

for all a, b that are elements of A. Where $P_j(a,b)$ shows the preference for alternative a over b as a function of $d_j(a,b)$ and

$$0 \leq P_j(a,b) \leq 1 \qquad \textbf{(2.25)}$$

Therefore, if there are any criteria where b is preferred to a, then $P_j(b, a) = 0$. Similar to ELECTRE, there must also be parameters signifying a threshold for indifference, q, and a strict preference threshold where the deviation is no longer negligible, p. These help to categorise the decision made into the one of six generalised criteria as shown in Figure 2.4.

Brans and Vincke (1985) outlined that for most real-world decision problems, these six general criteria will sufficiently represent the deviation in preferences in alternatives:

1. Usual criterion – there is strict preference of one alternative over another.
2. U-shape criterion – there is indifference between two alternatives up to the value of *q* where the preference is strict thereafter.
3. V-shaped criterion – preference of one alternative progressively strengthens until the value of *p*, where there is strict preference.
4. Level criterion – there is indifference between two alternatives up to the value of *q*, between *q* and *q*+*p* there is weak preference and after this value, there is strict preference.
5. V-shape with Indifference criterion – there is indifference up to the value of *q*, preference then grows progressively until the value of *p* where one alternative is strictly preferred.
6. Gaussian criterion – the preference of one alternative grows with the deviation between the alternatives. First, *q* and *p* must be set and the point of inflection of the curve, *s*, can then be established. The closer to *q* that *s* is, the larger the effect of a preference of an alternative will have in moving towards strict preference.

The next step is to outline aggregated preference indices across all of the criteria using equation 24 (Corrente et al. 2013), where for all *a*, *b* that are elements of *A*:

$$\boldsymbol{\pi(a,b) = \sum_{j=1}^{k} P_j(a,b) w_j} \qquad \textbf{(2.26)}$$

Where $\pi(a,b)$ expresses the level of preference for *a* over *b* (from 0 to 1) in all criteria and it is implied that the closer this value is to 0, the weaker the global preference of *a* over *b*. Equally, the closer it is to 1, the stronger *a*’s preference is over *b*. This leads to the calculation of the outranking flows of each alternative.

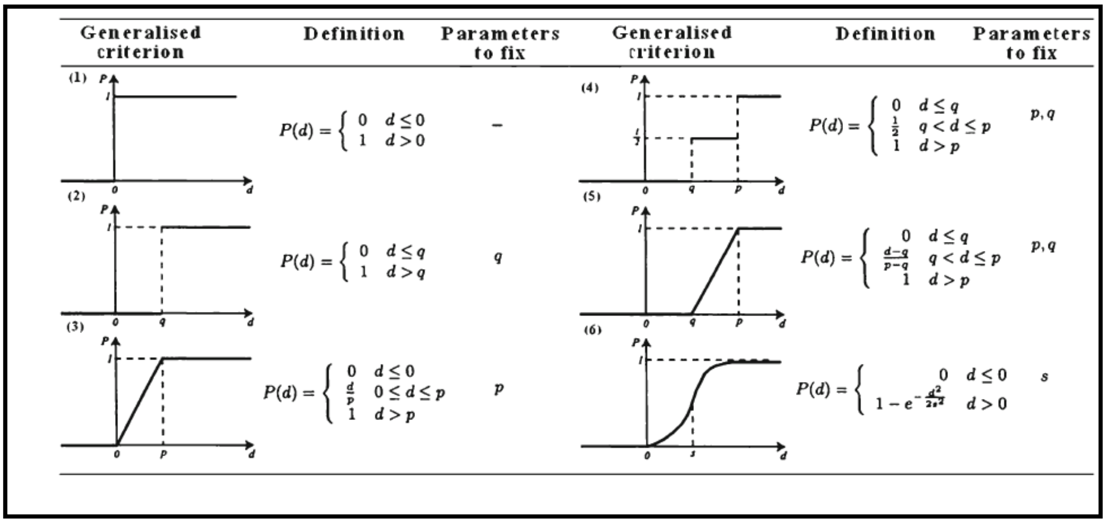


Figure 2.4 - Generalised Criteria applied to all criteria in PROMETHEE method – taken from (Behzadian et al. 2010)

How *a* outranks (*n-1*) other alternatives, is termed as its positive outranking flow and how it is outranked, is its negative outranking flow. The difference is termed the alternatives net outranking flow and all are defined by (Brans et al. 1984):

Positive Outranking Flow ➔ $$\boldsymbol{\phi^+(a) = \frac{1}{n-1}\sum_{x \in A} \pi(a, x)} \tag{2.27}$$

Negative Outranking Flow ➔ $$\boldsymbol{\phi^-(a) = \frac{1}{n-1}\sum_{x \in A} \pi(x, a)} \tag{2.28}$$

Net Ranking Flow ➔ $$\boldsymbol{\phi(a) = \phi^+(a) - \phi^-(a)} \tag{2.29}$$

It stands to reason, and backed up by Anojkunmar et al. (2014), that the higher the net ranking flow, the stronger the alternative has performed overall and the more preferable that this alternative becomes. Behzadian et al. (2010) provide a comprehensive list of the areas where PROMETHEE is used including environmental management, business and financial management, manufacturing and the energy industry.

As well as the methods outlined above, there are other OM that can be employed and a comprehensive survey of these is compiled by Figueira et al. (2005). However, ELECTRE and PROMETHEE are the most widely used.

2.4.4 Life Cycle Analysis

LCA is not a method of MCDA but is an environmental assessment methodology. As outlined in ISO 14040, Life Cycle Assessment (LCA) focusses the awareness of the importance of environmental protection and the impacts caused from the manufacture of products and their consumption (ISO 14040 1997). It evaluates a product or process from ‘cradle’, the extraction of raw materials from natural resources, to ‘grave’, its disposal. More than that, LCA covers the whole procedure for analysis and interpretation of results. It is used extensively in the analysis of energy from waste projects (Evangelisti et al. 2015; Astrup et al. 2011)

There are certain steps that must be followed for LCA.

2.4.4.1 Goal and Scope Definition

The intended application of the study must be outlined and be focussed before carrying out an LCA. To whom the results are to be communicated is also important. It is at this point that the specifications for how the study will be modelled and a plan for the project must be outlined. If ignored, results cannot be fully understood by those that need to know (Baumann and Tillman 2012). In the specification of the modelling of the project, the functional unit must be outlined. The environmental impact must be quantifiable in an understandable way that relates to the function of a product system, usually the system’s output (Xie et al. 2013).

Also, the types of environmental impact that are to be considered must be outlined to determine the parameters for data collection that will be carried out through the inventory analysis stage (ISO 14041 1998). Finally, the level of detail to be covered must also be specified to define whether site specific data will be used, or industry standards.

2.4.4.2 Inventory Analysis

The life cycle inventory analysis (LCI) involves the building of a model and an initial plan for the LCA according to the requirements set out during the goal and scope definition. Flow diagrams, similar to Figure 2.5, help to aid this process and provide an incomplete mass and energy balance for the system depicting only the environmentally relevant flows.

Once a flow diagram is created, the relevant data collection can be refined for that particular system. Figure 2.5 shows that at every stage, whilst the inputs and outputs of each process to be considered is essential, the transportation between each stage forms a large part of the analysis and must not be left out. To finish the LCI, resource use calculation and emissions of the system is required to produce results of the inventory.

2.4.4.3 Impact Assessment

The life cycle impact assessment (LCIA) aims to convert the information collected in an LCI into actual environmental impacts rather than just resource and energy use. Impact categories are created from the LCI results with specific category indicators, providing a LCIA profile that shows the 'environmental issues associated with the inputs and outputs of the product system' (ISO 14042 2006).

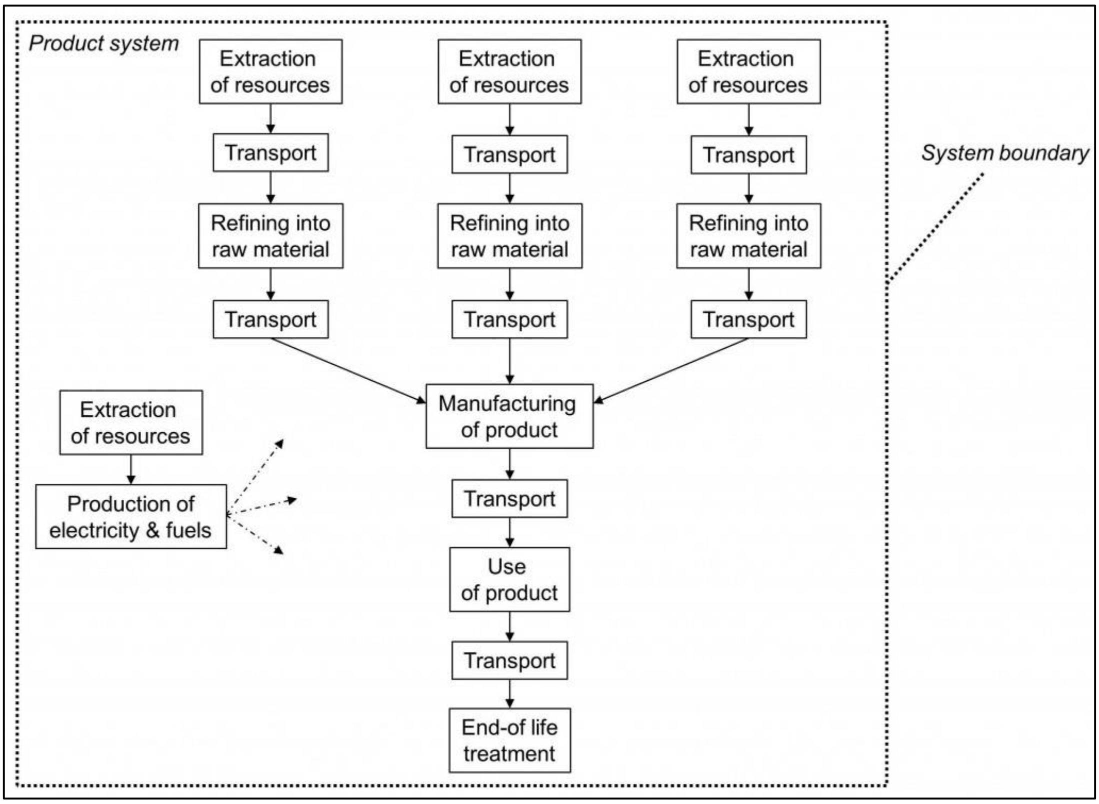


Figure 2.5 - Generic flow chart of a system showing the general areas of consideration for an LCA - adapted from (Baumann and Tillman 2012)

Once categories have been formed they must then be characterised to allow for the environmental impact contribution that each group have. Characterisation gives the size of the environmental impact of each category and, for example, all processes in a system that emit CO_2 will be summed to indicate their global warming potential. The same will be done with all other category indicators. The emissions and resource consumptions are the driving factors and a weighting is applied according to the overall environmental impact of each category indicator (Lu and Realff 2013).

Tunesi (2011) used LCA as the main methodology for a comparison of waste strategies in England. This is through the use of software developed by the Environment Agency called The **W**aste and **R**esources **A**ssessment **T**ool for the **E**nvironment (WRATE). The development underlines the fact that a decision on a local waste management strategy cannot be made using generic data; however it does show how certain strategies can be dismissed if they do not perform beneficially in environmental terms. The author states that cost and bankability is outside the scope of the paper, however does not state that other factors must be considered as well. Although environmental benefit *can* form part of the decision making process for infrastructure development, other factors such as the cost of building facilities and transport costs form a greater part of the process.

The major limitation of LCA is that it focusses solely on environmental issues. However, major decisions are rarely made on one such factor. Nearly all major projects or endeavours are decided upon with a multitude of different considerations. Monetary limitations, social acceptability and legislative constraints are usually considered alongside environmental impacts. For this reason, LCA can be helpful as a parallel decision aid to a decision analysis tool where required. There are examples of LCA having been undertaken in Russia (Tulokhonova and Ulanova 2013), China (Xie et al. 2013) and Columbia (Rodríguez and Sánchez 2014) in recent years to help aid decision makers in the field.

2.5. Decision Making in Waste Management and Associated Tools

The goal in most cases of waste management is to obtain an objective decision and create a balance between cost of service, environmental impact, demands for service and societal needs. Anyone involved with production, storage, collection, separation, transport, and treatment of waste is a stakeholder. In other words, this includes householders, members of authority concerned with waste collection strategy and members of staff.

There are many options for the treatment and disposal of LACW. These comprise of landfill, thermal processing (e.g. incineration, gasification etc.), composting, anaerobic digestion, preparation for reuse and recycling. Dependant on local factors, a combination of these processes is required to manage LACW. Drivers and barriers such as legislation and economic issues, as defined in chapter 1, influence the decision making process. No single solution can attain the best diversion from landfill in every single Local Authority (LA).

The flow of information between the Government, LAs and the contractors working on behalf of the authorities is not a complete one. Figure 2.6 shows how information is passed from one to the other, whilst feedback is not. The quantitative data that is reported back to LAs and Government do not tell the whole story.

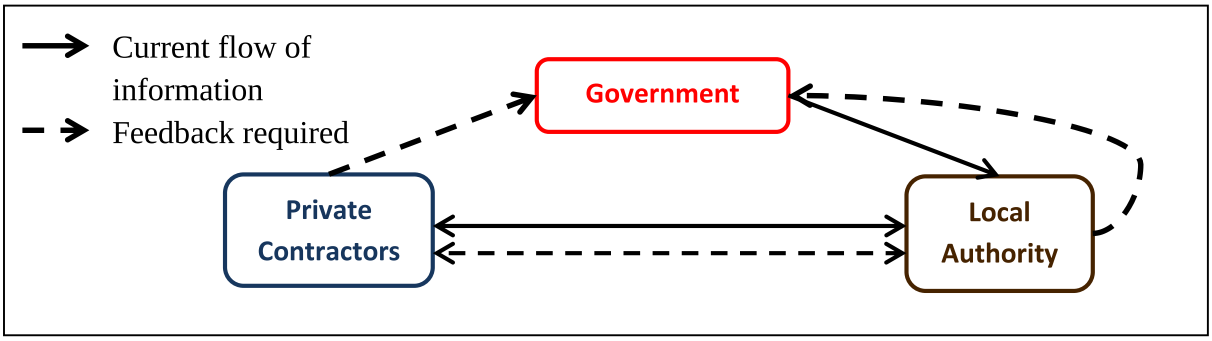


Figure 2.6 - The flow of information between main stakeholders

Decision support tools (DST) are used in every industry and at every level, from risk to waste management and managers to support staff. The primary objective when using such a tool is to keep operational costs low by avoiding wrong decisions being taken; ultimately losing time and money or possibly a negative environmental impact. Any decision making aid can be classed under the umbrella term of a Decision Support System (DSS), which is a system, specifically when computerised, that assists in the decision making process for an organisation (Turban et al. 2010). Therefore, in the waste industry a DST is not a stand-alone component but rather an amalgamation of many processes that involve quantitative and qualitative inputs. It has been recognised that MCDA of waste management using DST play a vital role, alongside human decision making, and have become invaluable (Hung et al. 2007; Chen and Chang 2000).

Without a robust decision making process, the reasoning behind any choice of collection method could be lost and not understood by at least one party. Most of the methodologies outlined have been implemented by those concerned with waste management. But they have been done so using decision support tools (DSTs) as required. The complexity of the methods requires aid so the decision process can be followed by stakeholders and the information loop can be closed.

In the waste sector, DST can be very complicated to create, due to the number of variables and complexity of the mathematical models, which include the assumptions and constraints required in decision making (Bani et al. 2009). In spite of this, there are many different approaches that have been undertaken to try and help ease the management of waste, with these varying constraints.

2.5.1 Decision Support for Oil Well Drill Cuttings

Decision support is needed to carry out Waste Management Plans (WMP), which detail how any operation is to deal with their waste. This includes application of the waste hierarchy, operating guidelines, making sure that relevant regulations are adhered to and the correct reporting and documentation systems are used (API 1991). In a report by Abbe et al. (2011), it was stated that oil well drill cuttings can be a high volume solid waste that could be diverted from landfill; if the right decision process are followed, with the relevant tool as proposed. This would lead to the waste producer being able to save money through landfill diversion, possibly achieve a revenue if it can be reused and move towards attaining any waste targets that have been placed upon the firm.

The tool that was proposed is a relatively uncomplicated one, in the form of a flow chart, as seen in Figure 2.7. This method is particularly clear and concise, with very obvious steps and procedures that need to be followed at every point. The key point in the diagram is the drill cuttings, which is highlighted. At this time, the cuttings undertake a detailed characterisation to determine the suitability for reuse and whether bioremediation is needed. In particular, it shows there is a need for flexibility in dealing with waste and can reflect technological advancement and regulatory changes, which can so often become overlooked where the environmental and economic impact may be the critical drivers. The key focus of this tool is on the environmental issues at hand, which is one major part of the thought process behind any activities currently carried out in the waste sector. However, this is not the only area that needs to be considered; the financial aspect is another key player when it comes to deciding how to manage waste. Unfortunately, a flow chart, such as this, does not have the capability of including the complex method of introducing economic factors into the process, which will ultimately form part of the decision making process.

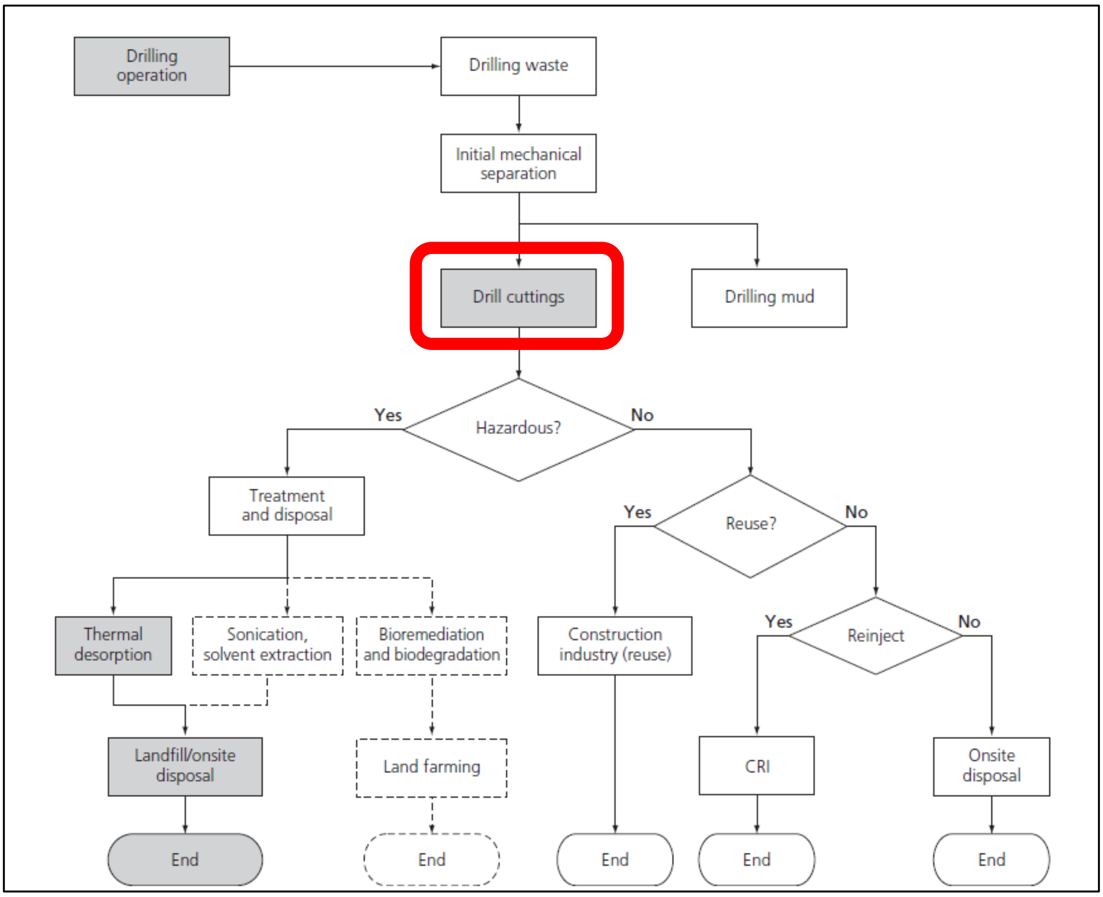


Figure 2.7 - Decision Support Process for Drill Cuttings management (Abbe et al. 2011)

2.5.2 ORganic WAste REsearch (ORWARE)

ORWARE is a simulation tool that was developed in Sweden, modelled using MatLab. The code originally, as the name suggests, only meant to deal with organic materials, but has since been developed further and can be utilised for inorganic materials too. The original main aim was to simulate the handling of organic waste in urban areas

(Dalemo et al. 1997). It has since been expanded to aid in the development of new waste management systems on any scale and is used to calculate numerous areas including costs, environmental impacts and substance flows. It does so by using submodels that can be transposed into a ‘master system model, representing the new or existing waste management system. Included in the tool is a method for taking into account compensatory processes for conventional production i.e. electricity use, heating fertiliser production etc. (Eriksson et al. 2002).

Figure 2.8 shows the concept of the submodel and how it is influenced by the inputs necessary to process the waste to avoid/limit the amount of material going to landfill and the subsequent uses that it may have. The secondary waste (e.g. incineration ash) is taken into account at this point, unlike other models, showing that certain waste treatment processes are not water tight solutions, and the consequences must be taken into account. Once these submodels are created, they can be located into the model of a waste management system, as depicted in Figure 2.9.

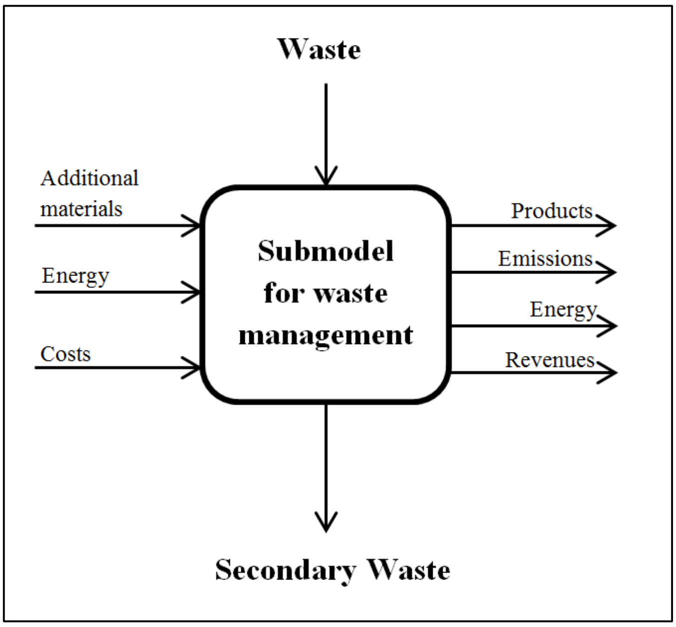


Figure 2.8 - Submodel used in ORWARE (Eriksson et al., 2001).

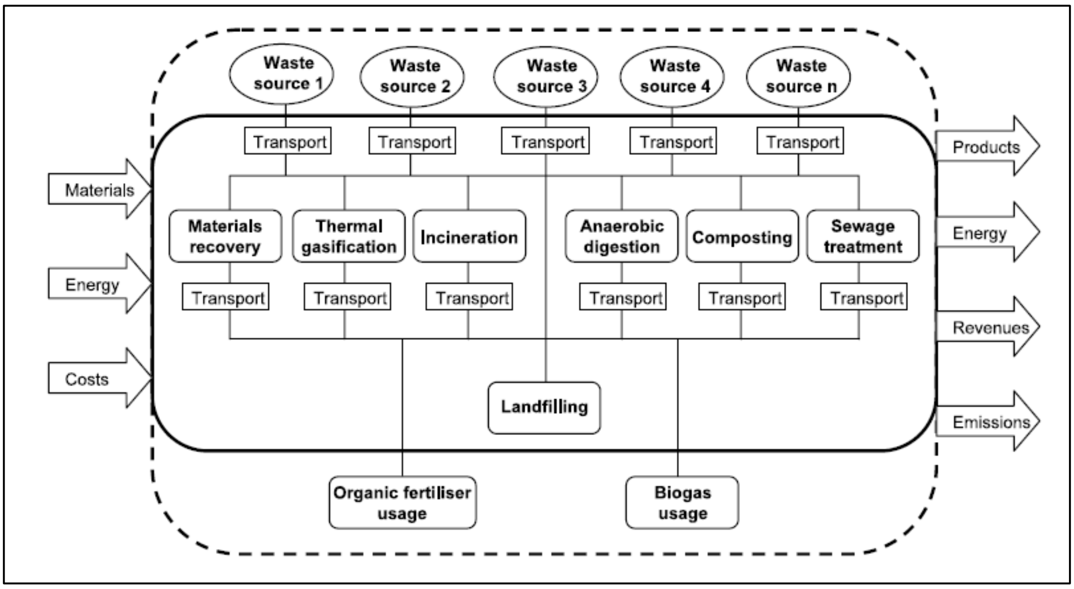


Figure 2.9 -Conceptual model of a complete Waste Management System (Eriksson et al., 2001).

ORWARE uses a combination of Life Cycle Analysis (LCA), setting the scope, undertaking an inventory analysis and impact assessment (ISO 14040 1997), and material flow analysis in which the static situation of different materials flows between subsystems in a defined system is described (Eriksson et al. 2002). This means that the environmental impact can be assessed of either various or singular elements, as they travel through the system and can therefore be compared as the system is changed to obtain the best overall outcome. As mentioned previously, one of the main advantages of this tool is that it includes emission and resource depletion irrespective of where it occurs. Some models can neglect to include this type of information if a secondary waste is created further up the chain, whereas it is included at every point in ORWARE. Also, the output of results from the model is displayed as a radar diagram, depicted in Figure 2.10, which makes comparison of environmental impacts much easier to carry out. By normalising all values to the reference scenario, which represents an impact value of one, all other outcomes can be compared in a very useful schematic. A symmetrical diagram shows equal importance for the criteria. On the other hand, ORWARE does not take into account costs associated with LCA, such as construction and demolition and loss on capital equipment, which are not included. This is a shame, as it is claimed that LCA is an integral part, but this should include every issue and not just environmental, if the model is to be used on a wider scale further than research.

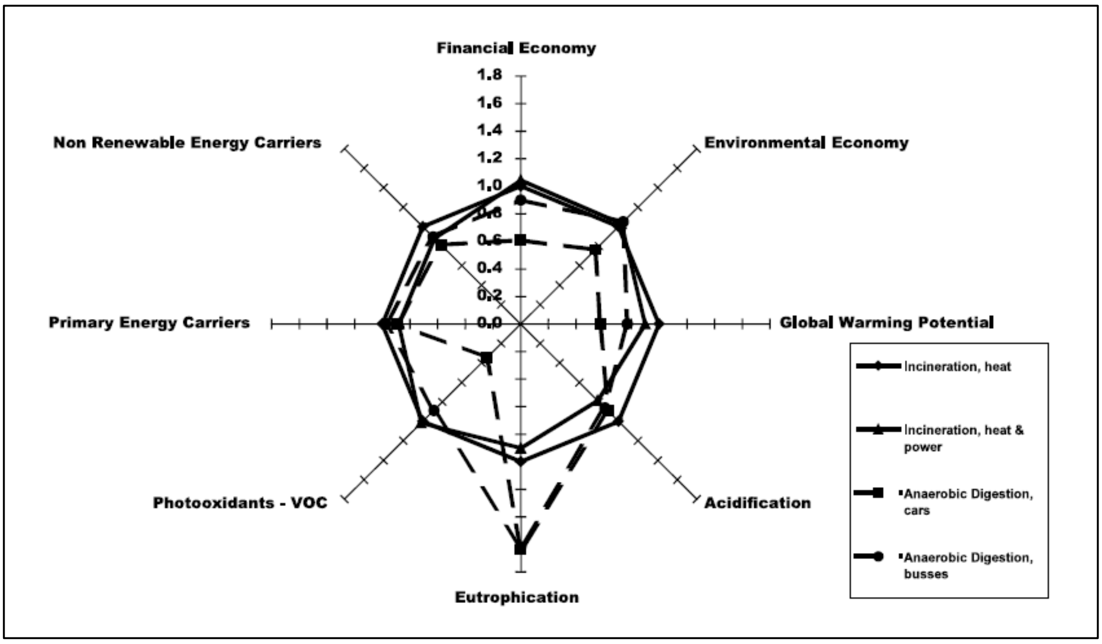


Figure 2.10 - Showing all impact categories from ORWARE in one diagram (Eriksson et al., 2002).

2.5.3 Solid Waste Integrated Management (SWIM)

The SWIM model was developed specifically with the aim of including and bringing together economic, environmental and social (EES) implications when managing waste. In particular post-consumer paper and cost analysis of weekly or fortnightly collections of recyclables (Wang et al. 1996). SWIM uses MS Excel as a platform and has been formed with a user friendly interface, which can be manipulated easily, whilst handling questions such as:

- *What is the most economically and/or environmentally viable collection system?*
- *What effect does a landfill closure have on a system?*
- *How effective are recycling systems for reducing waste to landfill*
- *'How can an economically sustainable, environmentally viable and socially acceptable waste management system be achieved considering the various options available?' (Wang, 2001)*

The SWIM model uses three smaller models within the system, to achieve the outcomes for the user. The process flow chart is shown in Figure 2.11, and, as can be seen, follows this methodology to ascertain the correct route. The first types are Demand Models that portray demand in services needed using generation and participation rates in recycling schemes. The second are Supply Models, which encompass all areas from operation of collection, to physical systems (e.g. location of facilities and collection frequency) and linking them to the demand side. Finally, Impact models handle economic data for carrying out the services and environmental impact data, in the form of carbon dioxide emissions, which are produced from operations. The main advantage of this model is that it sets out to include EES aspects of waste management and interlink them to create a system, or evaluate a current one, that can perform as well as possible, without being detrimental in any one area. For example, the cheapest possible WMS may not perform well environmentally; equally the best WMS environmentally, may have serious negative social and/or economic consequences. By including them all in one tool, any detrimental effects of one area on another can be evaluated and mitigated in the design process, rather than finding out after implementing a strategy.

The major drawback of the SWIM model is that it solely focuses on the collection and transportation system and not on the effects of managing waste and the consequences that are generated from processing the waste. This is unfortunate as the model, if developed, has the potential to become a complete evaluator and aid in the whole decision making process and not just the collection side. This may be due to the way that waste is dealt with in Australia, and that there is no need to take the analysis further, but Wang (2001) does hint at a possible inclusion of the model, within LCA analyses in the future which would dramatically improve the scope of the tool.

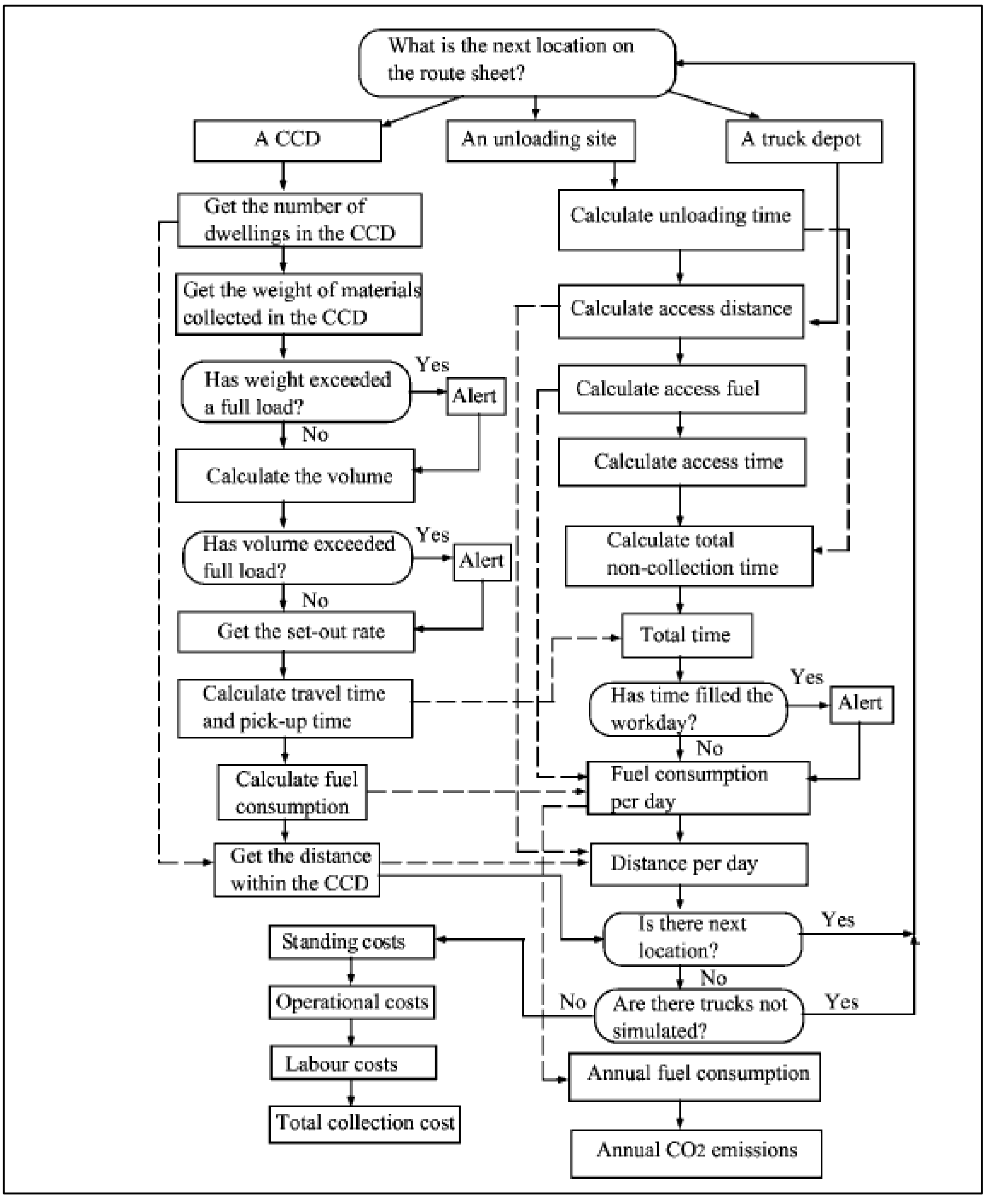


Figure 2.11 - Flow chart methodology of SWIM (Wang, 2001)

2.5.4 Used Tyres Resource Efficiency Tool

Through a joint venture between Waste Resource Action Programme (WRAP) and researchers throughout the UK, a tool to aid with how to deal with tyres when they become waste has been developed. Tyres are a specifically difficult material to deal with once they become waste, as legislation now dictates that tyres cannot be landfilled in the normal way. The Landfill (England & Wales) Regulations (2002) declare that, as of 2006, no whole or shredded tyres may be landfilled, unless for drainage applications. Curry et al (2011) state that there are three main methods in which used tyres can be recycled or reused to align with legislation:

- Baling – Used in civil engineering, forming highly compressed but lightweight blocks, bond by steel wires or straps that can be used as a like-for-like substitute for aggregate gabions

- Retreading – Retread tyres must pass the same safety standards as any new tyre and can therefore be assumed to be a direct substitute for new tyres

- Shredding – Used in civil engineering, cut into 5cm shreds, as back fill material in landfill (and act as a drainage blanket).

- Fuel Source – For example in the cement industry there are energy saving capabilities for the use of tyres in concrete production. Tyres can be burnt without flame or fumes thanks to the high kiln temperatures and when chemically treated, can be reused as a fuel (Bolden et al. 2013). The tool uses LCA when evaluating the impact of each route, taking into account all environmental impacts from 'cradle-to-grave'. Figure 2.12 shows part of this procedure, where the inputs and outputs of each method of reuse are outlined and their indicative values.

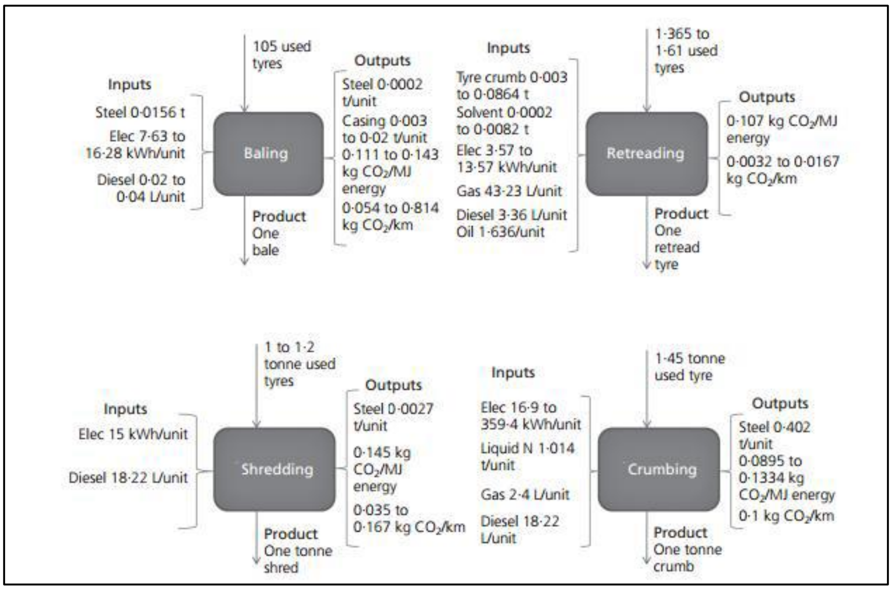


Figure 2.12 - Input and Output for each reprocessing technology (Curry et al., 2011).

LCA as a sole evaluator, must be taken with precaution, however, as there is currently a lack of guidance on methods and what data to be used is most appropriate for LCA

(Pennington et al. 2007). In spite of this, one of the advantages of this decision aid is that it takes into account the different types of treatment for the used tyres. Rather than requiring three different tools to operate, all analysis can be carried out from one central point to realize the best potential, both environmentally and economically, for the resources available. This is ideal when the future of the used tyres is undecided and if many projects could benefit from their use.

On the other hand, it has had to be limited to only three uses, as it can be difficult to make comparisons between certain applications. For example, during the development of the tool, truck tyre crumbing (for use in sports surfaces) had to be removed from the process, 'owing to a lack of comparability between the processes from which data were collected' (Curry et al., 2011). As can be seen here, what is perceived as a benefit can also hinder the tool. There needs to be compatibility when comparing processes, to give accurate and true outcomes. The tool is straight forward to use and has a user friendly interface which can be manipulated very quickly by the user without having to read any explanation on how to use it. The information required to be input is that which is easily acquirable, if not already in possession by the user and the results are understandable, mainly given as equivalent tonnes of carbon dioxide avoided and cost savings. It also indicates that should used car tyres be utilised in the place of virgin materials, the environmental damage is limited, but that, as expected, the economic cost is likely to increase. It is not clear, however, if this is in comparison to the whole life cycle of virgin materials and whether the cost of landfill/incineration is taken into account.

The supporting documentation claims that the tool assures 'the users and/or regulators that the outputs of the model are underpinned with a robust and standardised methodology' (Curry et al., 2011). The main benefit of this is that resource efficiency is improved with more materials being recovered and used as a substitute for raw materials, related to improved information dissemination. The dilemma is that, whilst the information gathered is wide and all-encompassing, the technical report cannot be accessed which describes this underlying LCA analysis. Recommendations have already been made by WRAP, suggesting that if access were granted to 'the technical report, a downloadable spreadsheet with conversion factors, a non-technical briefing and how it underpins the estimates' (WRAP 2006), then the tool would have a much wider appeal. As it is, the tool is likely to only be used at the scoping phase, to get a general idea of what might be the best route to take.

2.5.5 Other Applications

Over and above these specifically named tools, there are many studies that have applied the methodologies outlined above, to various waste management problems. The first is the proposal by Hokkanen et al. (1995), who applied the ELECTRE II method to a comparison of solid waste disposal methods with the following criteria:

- Political feasibility
- technical reliability
- transport reliability
- benefits to the national economy
- employment
- short and long term environmental effects
- environmental hygiene
- resource recovery level
- cost per tonne of waste.

After analysis, incineration was found to be the best choice, although the municipality they were modelling for decided to use the second best alternative, refuse-derived fuel (RDF) combustion coupled with landfill. Hokkanen and Salminen (1997) then used ELECTRE III, which allows for imprecise data, again to model a MSW management system in Finland, focussing on eight slightly changed criteria comprising:

- Cost per tonne
- acidic releases
- surface water releases
- technical reliability
- global effects
- health effects
- number of employees
- the amount of recovered waste.

This then gave the result in favour of RDF-combustion and landfill that was implemented in 1995. While they do not clarify the municipality in the original paper, it is assumed that these are the same case studies and it is a classic example of how the tool can be changed to fit for purpose.

Costi (2004) undertook an analysis using a generic model considering the technical, economic, normative and environmental aspects that face decision makers in the management of MSW and more specifically, the placement of treatment plants. It uses nonlinear optimization thanks to the constraints placed upon the situation.

De Oliveira Simonetto and Borenstein (2007) created **S**olid waste **COL**lection **D**ecision **S**upport **S**ystem (SCOLDSS) to look at vehicle allocation and their routing whilst simultaneously studying the amount of waste going to sorting facilities. The criteria were to seek optimal routes that reduce the amount of waste going to landfill and ensuring a minimum amount of recyclate to the appropriate facilities. It essentially uses pairwise comparisons of comparable trips i.e. they start and end at the same place as each other. SCOLDSS then uses submodels to model the network created and provide results accordingly.

AHP has been implemented for an analysis of waste treatment options in Boston and allowed the development of four situations depending on the contribution of different stakeholders (Contreras et al. 2008). Biogasification was found as the most preferable method of treatment thanks to a high importance being placed on greenhouse gas emissions and limited landfill capacity. The clarity of AHP and its pairwise comparison method was found to be highly favoured for the situation.

Karagiannidis and Moussiopoulos (1997) applied ELECTRE to the waste situation in Athens, Greece, and the decision between using landfills only, Materials Recycling Facilities (MRFs) or separate collection. Considering the date at which this was carried out and for Greece (that have one of the worst recovery rates in the EU), this was very forward thinking. They found that the collection of source segregated material came out best, as the reliance on MRFs may hinder a commingled collection approach.

2.6. Discussion

Some of the tools outlined for use in waste management, use classic DM methods such as Outranking and MAUT, whereas others have less defined structures. It is very difficult to model a whole WM system when taking into account all the general areas of criteria (environmental, technical, economy, social), hence models generally focus on various aspects of waste management.

It has been shown that MCDA is very good at handling both qualitative and quantitative data whilst making group decision making possible across a broad spectrum of industries. For waste management, this is ideal as it is usually more than one person who inputs into the decision making process and opinions can affect the decision making process in an important manner. Most applications of the methods, i.e. the models, look at refining the underlying technique and many of them are very theoretical. For a theoretical understanding this is ideal, but for a real world application, the methodology would be more suited to looking at how to select solution alternatives (De Oliveira Simonetto and Borenstein 2007). The focus needs to be on whether the alternatives achieve the goal set out and also that it is acceptable socially, economically ideal and environmentally effective. If not, then the type of methodology used is irrelevant.

Also, the very nature of MCDA makes it very difficult to assess if one method is unequivocally approved over any other. As a whole, it is very varied and this study of the available literature unveils many benefits as well as problems. The first area to address is the large number of methods and subsequent tools available to stakeholders in waste management, or indeed any decision making environment. Whilst this can be perceived as strength, it could also be construed as a weakness (Guitouni and Martel 1998). With so many options available, it is nearly impossible to study every methodology and decide on which is perfect for the decision making process at hand. On top of this, once the DM has narrowed down the options, a decision making process in itself is needed to select a method, creating somewhat of a paradox. The question is, how can a method be chosen objectively?

Truthfully, there is no objective method. Once someone understands and affiliates themselves with something, they will naturally have an attraction and be more biased towards it. However, there are also objective ways in which to discount some of the possible methods. For a waste management situation, social acceptance is required, thanks to its impact on perception and participation rates in a collection scheme (Hung et al. 2007; Nilsson-Djerf 1999). Therefore, qualitative, as well as quantitative data will be used, and any method that cannot deal with both can be rejected.

Some methods of MCDA cannot adequately model the problem outlined. Waste management has many layers embedded in its composition and requires segregation to be able to understand fully. For example, where cost is a consideration, there are many types that input into the decision e.g. cost of fleet, workforce, servicing, fuel etc. If this is not provided for, the method can be discarded.

In a waste management context, the two most likely used methods would be OM (in the main ELECTRE) or AHP. Of these outlined methods, ELECTRE and PROMETHEE are very capable in their application. However, there are some authors who outline a problem in the allocation of weightings, indifference, preference and veto thresholds. As these are subjective, they can easily be set to individually affect the outcome. In comparison, AHP uses the pairwise comparison to set these weightings through the hierarchical nature.

The use of the concordance and incomparability statement in the OM, is a strength. If there is insufficient data to directly compare two criteria, then this is allowed for. In contrast, AHP dictates that there must be direct comparison. It can be argued that for a meaningful analysis, every part of investigation should be compared and if it can't, it should not be included. In practice, this is nearly impossible as it is not always possible to obtain all the data necessary.

A short coming that was observed with AHP was the phenomenon of rank reversal. This involves the introduction of a new alternative that once compared to all criteria and alternatives, can completely change the preference order of the alternatives (disrupt rank preservation). Saaty shows that by the introduction of an 'irrelevant' alternative, rank can be preserved if one wishes (Saaty 1994). Alternatively, Saaty and Sagir (2009) address the issue further and conclude that sometimes, it is necessary to accept that the introduction of a new alternative will indeed require rank reversal with examples.

The starting point for AHP is the definition of its goal and thereby identifying the main issue. This falls in line with the decision making framework laid out in Figure 2.1. ELECTRE and other OM start with the outline of the solution alternatives as the first step. Not only does this contradict with how a decision making problem should be set up, but it can make it difficult to follow the thought process in a logical manner.

LCA can be used in the waste management context. Although not a method of MCDA, it provides analysis for the environmental impact. Financial implications must be modelled, social acceptance must be accounted for, legislative compliance must be checked and environmental impact should be kept as low as possible. However, an LCA is only required, in a Welsh Local Authority context, when specifically trying to prove that another manner other than Kerbside Sort collection, is more beneficial. For this reason, LCA is undertaken *after* the decision making process and is not a necessity since a number of other key parameters will have a greater impact.

The author proposes the use of AHP as a method to assist Local Authorities in the choice of waste collection method. Quantitative and qualitative data can be processed together and an understandable output for the stakeholder(s) can be produced. AHP has never been applied to Welsh Authorities in trying to aid the understanding of their decision making process. To the author's knowledge, neither has it been applied in a decision support tool with a focus on a suggested best method of collection, given the conditions and parameters at the time of study.

The research is trying to bring objectivity to what is essentially a subjective area. The Welsh Government are resolute that Kerbside Sorting is the way forward. With less than half of the authorities in Wales using Kerbside Sort collections, their opinion is that commingled collection is more appropriate. The research attempts to take in to account opinions and data, whilst providing as objective a result as possible at the end.

3. Case Study Authority

3.1 Introduction of the Case Study Authority

In the UK, municipal waste is estimated at 21.6 million tonnes and in Wales, there was a total of 1.6 million tonnes of municipal waste generated in 2013/14 (StatsWales 2014a).

Ceredigion is a rural authority on the west cost of Wales, as highlighted in Figure 3.1. It covers an area of approximately 1795 kilometres squared (km^2), ranking it the 4th largest authority in terms of area in Wales. As per the census of 2011, Ceredigion contains 75,922 residents ranking it 19th in terms of population size (StatsWales 2011), equating to a population density of 42.3 persons per km^2.

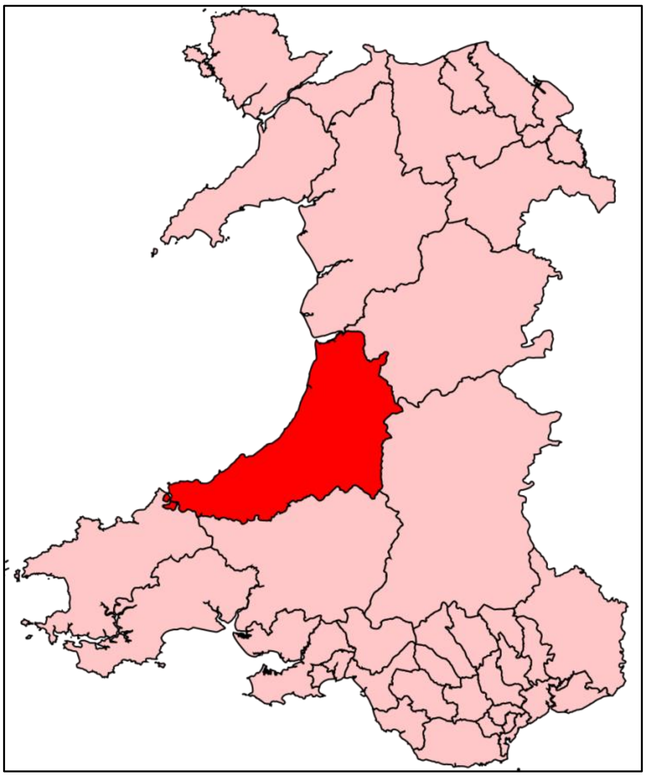


Figure 3.1 - Map of Wales showing Local Authority Boundaries with Ceredigion highlighted in red (Wikimedia 2014)

LACW collection in Ceredigion currently serves 34,500 households leading to a generation of 33,828 tonnes of MSW in 2014 (StatsWales 2014b). Figure 3.2 shows that the composition is 14,366 tonnes of residual waste, 12,773 tonnes of reused/recycled waste, 5,142 tonnes of food waste and 200 tonnes of green waste collected in 2013/14. The remainder is composed of non-household waste. The sum of recycled, food and green waste is 18,115 tonnes. When divided by the total generation value of 33,828 tonnes, it gives a total combined percentage of approximately 54% of LACW from households being diverted from landfill.

Historically, Ceredigion have the following reuse/recycle/composting rates for collection:

- 2008/09 – 48.7%
- 2009/10 – 48.5%
- 2010/11 – 51.4%
- 2011/12 – 58.4%
- 2012/13 – 53.6%

This shows that rates have steadily been increasing year on year and the Authority is ahead of the targets set out in the Waste (Wales) Measure (2010) for 2013/14 of 54% diversion through recycling, preparation for re-use or composting. In 2013, the definition of the reported rates changed from "municipal waste 'collected' for reuse/recycle/compost" to "municipal waste 'sent' for reuse/recycle/compost" (StatsWales 2014), hence a lower rate for 2012/13 than 2011/12.

Presently, the Authority run a fortnightly collection for residual waste for householders own bags, weekly collection for food waste using caddies and garden waste on demand using bags where a fee is charged. The recycling is collected via a commingled collection weekly using clear bags.

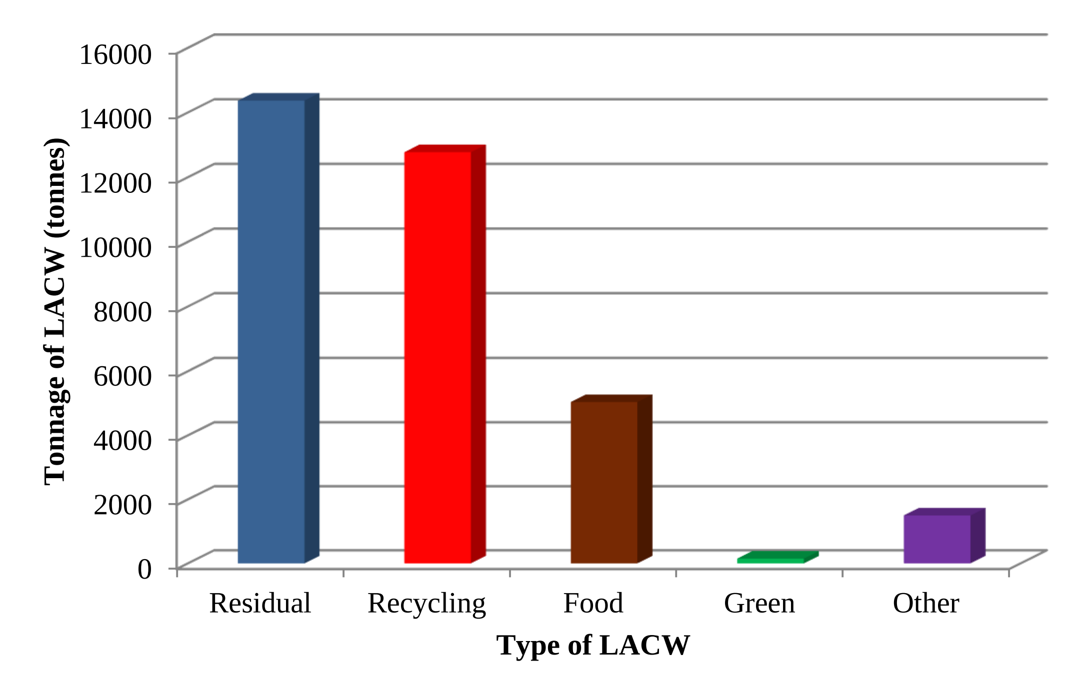


Figure 3.2 – Composition of MSW collected by Ceredigion in 2013/14

3.2 What are the Drivers and Barriers LAs face?

Before deciding upon the methodology to be used, an understanding of the drivers and barriers that affect any Local Authority (LA) was needed. By understanding what pressures are applied to LAs in relation to MSW management, a suitable set of criteria to analyse the decision making process can be outlined.

The first question to ask was in theory, when not considering legislation, 'Why would a LA want to divert waste away from landfill, when it is the cheapest and easiest option?' If it were not the cheapest and easiest option of managing waste, other methods would have been implemented in the first place. After a study of the literature and many meetings with LAs, members of Welsh Government and landfill and MRF operators during the initial part of the study, these were identified as outlined in Figure 1.9.

Legislation is the main barrier to landfill. The environmental implications of sending all waste to landfill are large; mainly in the release of methane from the uncontrolled breaking down of organic matter. The release of greenhouse gases (GHG) such as methane and carbon dioxide (CO_2), into the atmosphere, has a detrimental effect on the environment. The subsequent financial penalties that have been put in place by legislation, also contribute as a barrier to landfill.

The space required for landfill is large. In urban areas and main cities especially, the cost of land is very high. This is a major driver for LAs dealing with landfills that are close to maximum capacity, to find alternative methods for disposing of materials that have become waste. Existing landfill sites, with spare capacity, are not a problem logistically, however trying to buy land for new sites is and can be very costly. For this reason, land available for new landfill sites is not in abundance and therefore capacity is running low (De castella 2011).

The drivers for a LA to divert waste from landfill begin with the possible monetary gains. The conversion of seeing waste as a resource rather than something to be discarded allows for a market place for such items. The separation and processing (where required) of these materials can create an income through their sale, for the LA or the Waste Disposal Authority. As waste management (WM) is an ongoing concern, systems and infrastructure have been put in place over many years, in some cases by private entities, thereby reducing the amount of initial investment required by the LA.

In addition, the positive publicity that results from positive environmental actions can cause an increase in the participation rates. If the general public believes that what they are doing is making a positive impact then they are more likely to participate (De Feo and De Gisi 2010).

The amount of energy saved and the reduction in pollution through diversion of waste is also a driver for LAs (WAG 2009). The savings are generally quantified through a comparison of the amount of virgin material that would have been extracted against the energy used to repurpose the material so that it can be used again. The reduction of the production of GHG which occurs in landfill is the main source of the reduction in pollution. The commitments of member states to the Kyoto Protocol (UNFCCC 1997) and its amendments (most recently the Doha amendment, yet to be ratified) drive countries to reduce their pollutant emissions. Effective WM can aid in achieving these targets in reducing emissions.

The barriers to waste diversion are twofold. Is there enough capital to deal with a change and also is there enough divertible waste to make this, and further investment, viable? Concurrently, the drivers are the legislation set out through the Landfill Regulations and Governmental direction through Landfill Tax Regulations and accompanying strategies outlining targets.

The Waste Hierarchy suggests how a LA should deal with MSW. Figure 1.5 outlined the hierarchy but when viewed from the perspective of a LA, there is a different emphasis. With regards to the reduction of the amount of waste produced, for a LA, this can almost be counterproductive. They are set targets for preparation for reuse, recycling and composting/digesting according to the percentage of MSW collected. The fewer materials that are being disposed of, the less reusable/recyclable/biodegradable material that is potentially available to them.

The biggest barrier facing the implementation of reuse methods is that most publicity and the majority of funding are aimed at recycling. This is predominantly (and speculatively) because recycling is more readily observable than other forms of diversion and impacts greatly on the way that householders dispose of waste. However, charities that can use these materials have a lot to gain, partly through tax relief and added income.

Recycling is the level of the Waste Hierarchy that demands the most attention from a LA. It is the service that householders are mostly affected by and have a large influence over. Figure 3.3 shows more specific benefits and limitations of dry recycling i.e. excluding food waste and green waste, and the differing methods of collection. The main benefit of a kerbside collection of dry recyclate is the ease of use for householders. They do not have to travel to dispose of waste and this is done on a regular basis. It is the most economical way, for householders and the LA, to include as many households as possible in the collection of waste.

In contrast, Figure 3.3 also highlights the logistical issues such as difficulty in collecting from flats and if it is a rural authority, they must collect from densely populated areas as well as sparse areas. Furthermore, there are the cost implications, legislative implications and social issues. Do the householders understand the problems with contaminated recyclate? Do they want to participate? The LA must consider legislative changes and whether their fleet can accommodate these changes too.

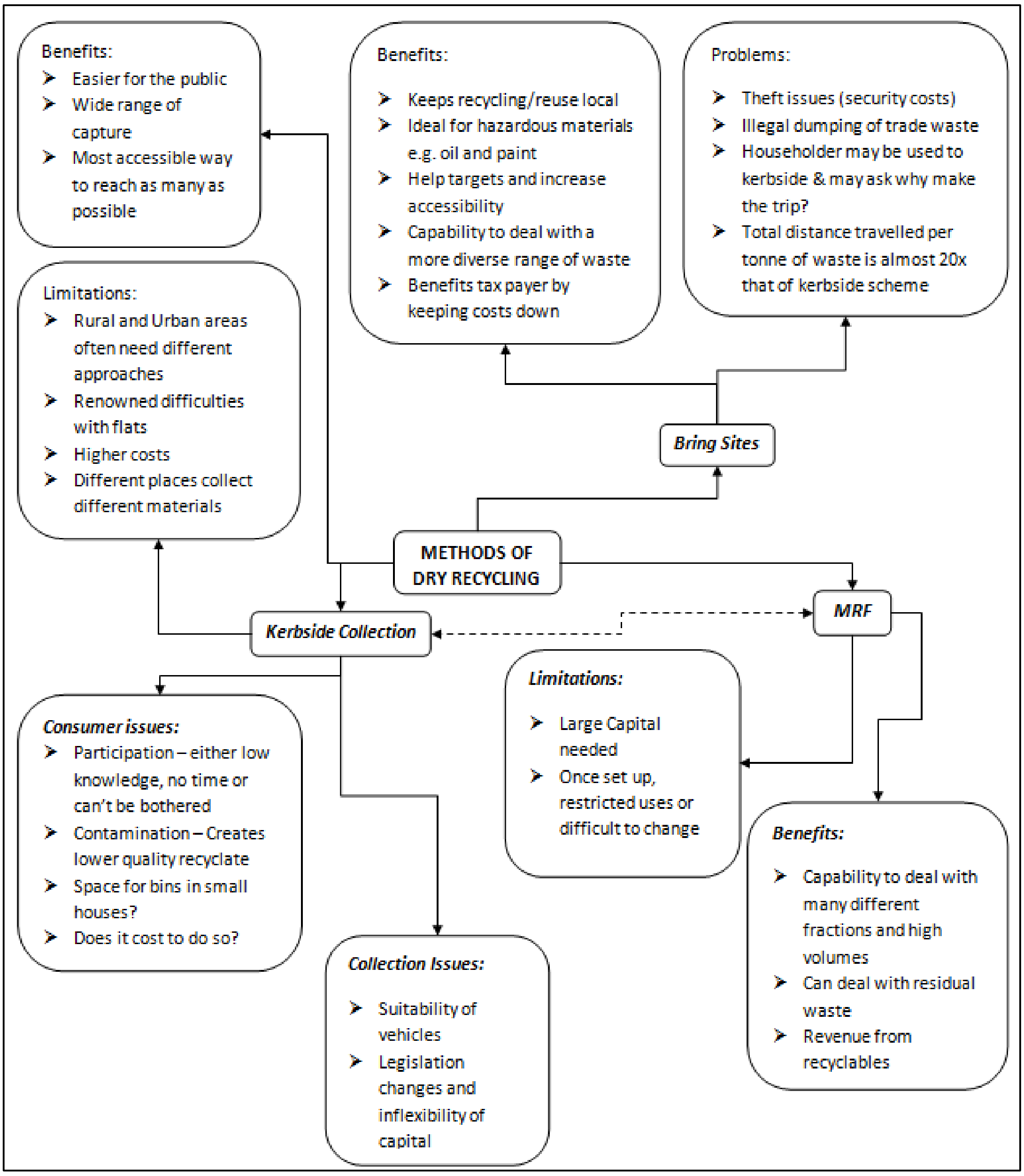


Figure 3.3 – Benefits and Limitations associated with the collection of dry recyclate

The problems mentioned above are from a kerbside collection. The benefit is that this leads to greater range of capture and is much easier for the general public than taking waste to a bring site. However, a bring site has advantages when used in parallel to a kerbside collection. A bring site allows for a more diverse range of waste to be dealt with and can aid in achieving recycling targets. It has the added benefit of keeping recycling local to the authority which encourages local residents to participate and can have the added effect of keeping costs down, which translates to savings to the tax payer (local residents). However, there are increased security costs to combat theft of valuable materials and may lead to the illegal dumping of trade waste. The householders may also question why they should use a bring site when a kerbside collection could be used to collect their waste at no added cost to them.

3.3 The decision made by the Case Study Authority in 2010

In 2010, Ceredigion County Council (CC) evaluated the recycling facilities they provide within the county. This was as part of increasing efficiency and saving on costs in their refuse collection service (Cerdegion CC 2010).

Eight options were considered by the council and the waste management team and were highlighted as:

- (A) – Weekly collection of recyclate in a survival bag, in order to keep this stream separate, and residual waste in the same vehicle sent for processing in a MRF. Not available to all households in the county. This was the current system at the time
- (B) – As (A) but with a trial of food collection in one town
- (C1) – Weekly collection of recyclate and food using a split body vehicle and weekly collection of residual waste in a Refuse Collection Vehicle (RCV)
- (C2) – As (C1) but a fortnightly collection of residual waste using RCVs
- (C3) – As (C1) but a kerbside sort collection of recyclate
- (D) – As (C1) with no separate food collection

- (E) – A hybrid system. For urban areas, as (C1). For rural areas in the South of the county, as (A) and for rural areas in the North, no kerbside collection. All rural areas would be offered a home compost bin
- (F) – As (A) but for the whole county

These options immediately represent the logistical problem of dealing with a region that had both rural and urban areas. With differing population densities within the authority boundaries, identifying optimal collection routes using a homogenous fleet of vehicles was very difficult. Options A, B, E and F require specialist routes and vehicles that differ depending on the area.

At the time, the Welsh Assembly Government (WAG) offered an increased Sustainable Waste Management Grant (SWMG) of £752,021 to aid in their drive to comply with the EU Landfill Directive (Cerdegion CC 2010). A portion of this amount was provided specifically for the collection and treatment of food waste. In view of the SWMG and to align the authority's collection scheme with that of the WAG, the decision was taken to exclude options A, D and F from the evaluation as they did not feature a separate food collection.

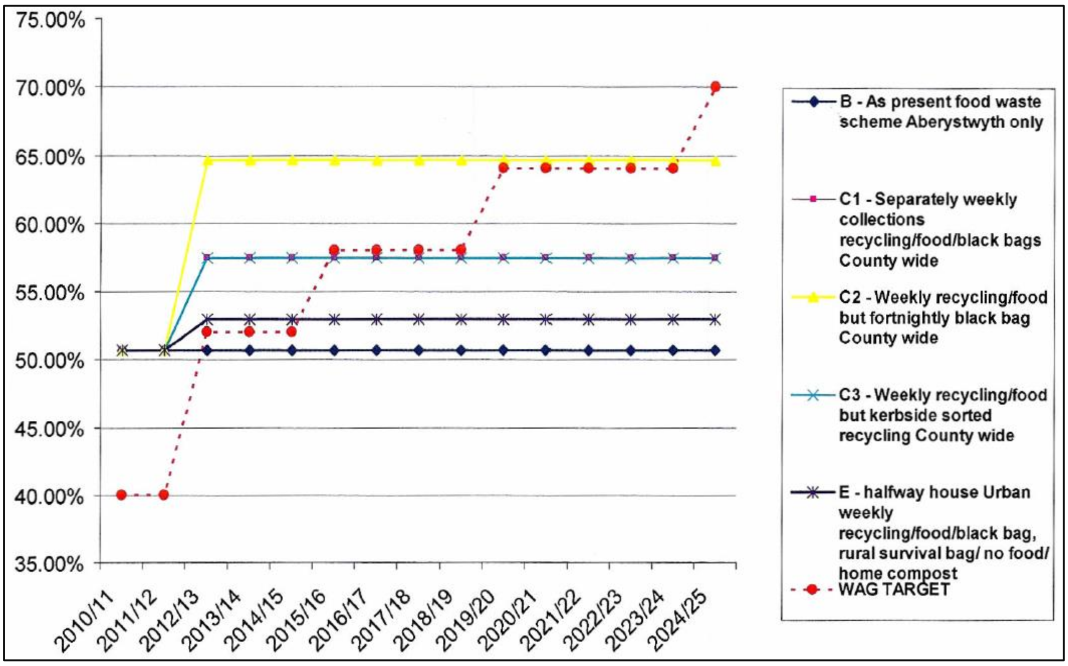
Other drivers for the initiation of this evaluation included the authority needing to decide on the future direction of their waste collection, so new tenders for waste management contracts could be formed. This was partly because the current fleet at the time was overdue for replacement and the decision for the type and number of new vehicles was required. Also, how food waste was to be treated was still in question and a decision was required on how much food waste could be collected that would help form the decision for the method of treatment.

All the costs involved for the remaining five options were then calculated, as were the likely environmental and diversion performances in achieving the targets set by WAG through the Waste (Wales) Measure (2010).

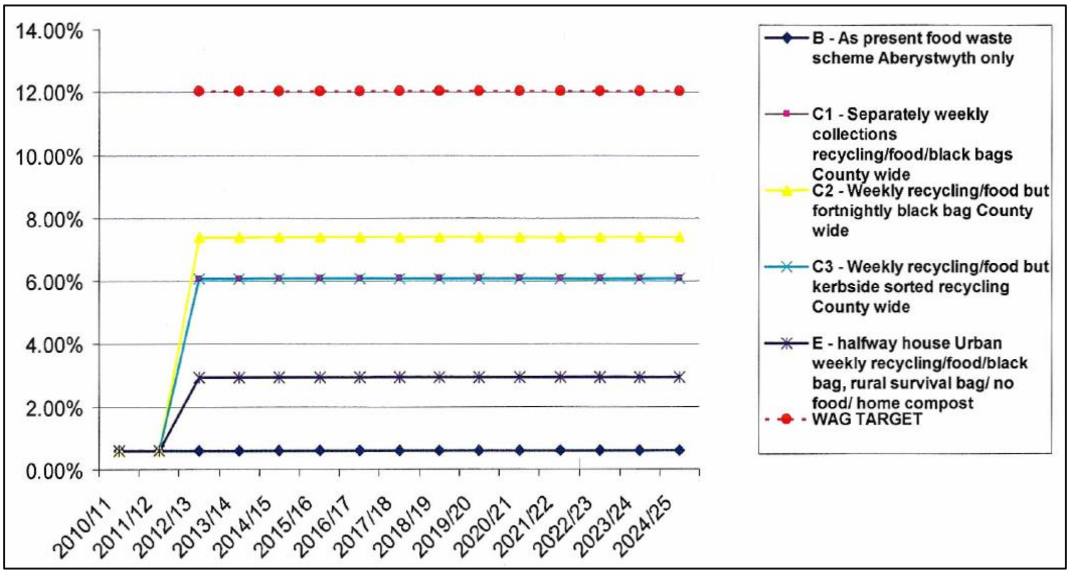
Figure 3.4 shows that in the long term, none of the options were predicted to achieve the target of 70% diversion for recycling/composting by 2025 set by WAG or the 12%

target for food collection. In hindsight, these values were incorrect as the rates were incremental, outlined in Section 3.1, rather than a step change and plateau. The rates also surpassed these estimates.

It was concluded by the council, that all the options would require an increase in cost of operations (Ceredigion CC 2010). Option C2 was adopted as it predicted the best outcome in diversion rates, environmental performance and the increase in cost could be offset against the future savings in disposal costs and avoided penalties. Also, with a fortnightly collection of residual waste, it was thought that public participation would be improved as this would encourage the use of the recycling and food collection services. It was stated that for these statistics to come to be realised, a robust communications campaign would be required as the data provided was based on high performing models across the UK.



a - Recycling/Composting



b – Food targets

Figure 3.4 – Indicative performance of options against WAG targets for (a) recycling/composting and (b) food waste (Cerdegion CC 2010)

3.4 Summary

As per the Guidance given by Welsh Government in a consultation document regarding the separate collection of recyclate streams (Welsh Government 2014),

> *"The terms "necessary", "practicable", and "all reasonable measures" are value judgements. The relevant establishment or undertaking will need to consider local conditions and look at what can be achieved in comparable situations elsewhere in Wales or the rest of the UK."*

This paragraph emphasises the need to consider the situation for each authority individually and consider the influencing factors that drive the decision making process. All of the considerations summarised in this chapter must be incorporated into the decision process of a LA. There are many issues and they vary from quantifiable criteria, such as cost, to criteria that require a judgement based on the expertise of those involved in the decision making process. This has to be in a logical manner that can express all of the benefits, limitations and other issues for the collection of MSW, in a comparable way.

By outlining the need for a recognisable methodology in the Decision Making Process, a local authority can follow a logical route and avoid the trap of focussing solely on financial implications.

4. The Iterative Methodological Decision Making Process

4.1. Introduction

As previously outlined in Chapter 3, there are many methodologies that can be used to solve various aspects of decision making related to solid waste management (SWM). Analytic Hierarchy Process (AHP) was selected for the following reasons.

1) Ease of use – The methodology was viewed to be the most logical to use when viewed from a user's perspective. The difficulty with the other methods is that they require specialist knowledge in their use. The ease of understanding means the decision maker can appreciate what information they are entering and what input this has to the process. It avoids the blind entering of numbers into a computer program to get a result, giving 'a more reliable outcome. Simpler tools are easier to use and therefore more likely to give accurate results (Edwards and Barron 1994).
2) Apposite for the decision – AHP structures the decision making process for SWM very well. It allows a clear breakdown of criteria and sub-criteria to model waste management and allows a clear comparison of the alternatives.
3) Effective modelling – The methodology is easily implemented in full in a Decision Support Tool (DST) and could be done through software that is in common use. This allows a certain amount of familiarity, rather than having to use a new type of software for user input.
4) Quantitative and Qualitative data – Both types of data are required when going through the decision making process of selecting a SWM system. AHP comfortably deals with either type of data in a way that can easily be understood. It also allows for their simultaneous use.
5) AHP starts with the definition of a goal and not from the selection of criteria – This is ideal because there are many aspects to SWM and deciding which area to focus on is most important. In this case, it is the collection of waste that is of interest and by defining exactly what is required of the methodology, the decision making process can be studied.

The process for using AHP was outlined in section 3.4.2. The remainder of this chapter is devoted to the development of the decision making process with the development of AHP and the tool. First, the decision making route map is followed to outline the determination of the evaluation criteria, the alternatives to be used and the development of a subsequent DST using MS Excel. A typical process flow sheet that a user must follow is highlighted in Figure 4.1.

4.2 Limitations and Initial Assumptions of AHP

As with every methodology, there are some limitations in using AHP and some assumptions must be made before embarking on the decision making process.

4.2.1. Limitations

The following limitations apply:

1) It is not possible to carry out full analysis of frequency of collection due to sheer number of permutations of collection variables. This has been decided to not be necessary since the increasing general agreement that recyclate and food waste is collected weekly with residual fortnightly. Therefore, a more basic version can be used in the process.
2) The method cannot currently study food waste collection at the same time as recyclate. To directly compare these two waste streams is very difficult, especially as there is separate legislation and very diverse cost differences. However, food waste collection will still be used as a checking mechanism.
3) The method cannot undertake route optimisation. Other methods must be used to obtain a large amount of data for the analysis, in terms of cost and environmental effects.

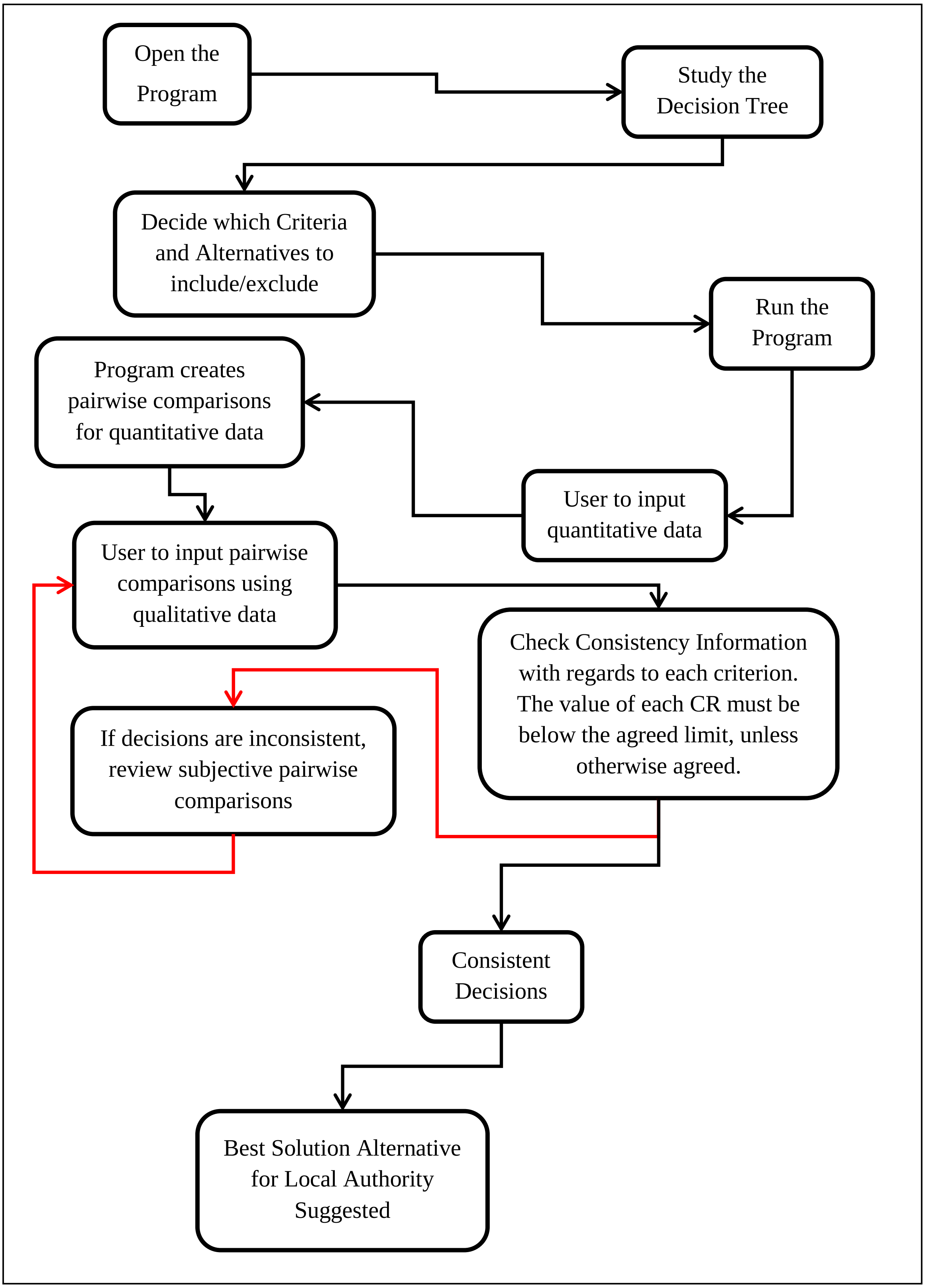


Figure 4.1 – Typical Process Flow Chart with iterative routes highlighted in red arrows

4.2.2. Assumptions

The following assumptions are made:

a) The frequency and types of collection can be modelled in a realistic way. In practice this needs to be done, however it takes a whole entity (such as WRAP) to undertake this.
b) For each criterion or solution alternative, the performance in relation to each other can be evaluated on a common ratio scale and can be quantified.
c) The user will not be biased towards their current method of collection.

These assumptions were formed to initiate the development of the DST. They will be re-evaluated after testing phases as outlined in this chapter.

4.2.3. Impacts of Limitations and Assumptions

The first limitation has the effect of restricting the scope of the study. It requires huge amounts of data collection to be able to model the various combinations of municipal solid waste (MSW) collection. With over twenty options of recyclate collection coupled with the possibility of separately collecting food, recyclate and residual waste on weekly, fortnightly and three weekly bases, there is the potential for over 500 permutations of MSW collection. For the case study Local Authority (LA) to gather information of that scale is not plausible and would not be necessary. This is also not necessary. They can realistically narrow the number of scenarios that need to be studied, by eliminating those that would never be implemented.

To overcome the limitation of analysing food waste collection and disposal, it will eventually be used as a method to check the validity of the best outcome. This will not become clear until the fourth iteration of checking the process; however, it is important to address this issue early on. If the mode of collection, with a basic analysis of food waste, matches the best outcome for recyclate collection, then there is consistency in the results. This provides a ‘bottom up’ analysis in comparison to the ‘top down approach’, employed in the analysis of recyclate collection.

With the case study LA undertaking a route optimisation exercise, there can be a narrowing down of the available options. If certain methods of collection are not operationally possible due to the layout of the county, it aids in the reduction of the number of possible alternatives and provides much of the information required for analysis. The impact is that the decision maker(s) begin to understand the areas they must contemplate, in addition to the data at hand, to form the final decision.

By assuming that all the criteria and alternatives can be compared on a ratio scale, the decision making process is simplified for the user. This should allow for a better understanding of which criteria supersede others and by carrying out pairwise comparisons in this way, it will guide the user to choose whether they want the individual criteria included in the analysis.

The bias that can be shown by a stakeholder can have an effect on the outcome. For the case study LA, it can be a natural step to have favouritism towards their current method of collection, as they know it currently works. Data for other collection methods may be correct in theory, but there is an element of the unknown as to whether they work in practice. Subjective judgements are, in their essence, based on opinion, but these must be made without prejudice against an alternative without sound reasoning. Otherwise, the decision making process is compromised regardless of the methodology and the result will not truly reflect the real world situation.

These assumptions and limitations are revisited after testing the methodology and DST throughout this chapter.

4.3 Setting up the Hierarchy – The Decision Making Route Map

The first issue to tackle was setting out the problem in terms of the decision making route map. Going through the process in the eight step manner, provided a way to document clearly how the final criteria and solutions were to be laid out. This was carried out for recyclate collection specifically. Although food collection is very important to the collection process, it is somewhat dictated to, by the method of recyclate collection. For example, if the recyclate collection is chosen to be a kerbside sort (KSS), then the use of a split body vehicle is not required and a dedicated food vehicle is most likely to not be required also. Instead, it will be used as ‘bottom up’ approach to check the decision made using the ‘top down’ approach of the AHP, outlined later in the chapter. The check will be in terms of whether the recyclate collection decision matches real life decision making logic, rather than trying to appease the mathematical process.

To aid in the definition of the problem, Figure 1.9 showed the drivers and barriers to each step of the hierarchy and hence the route to the approach. This was achieved through research, progressive meetings with Councils and various external discussions. The overall definition of the problem for AHP is ‘What is the best method of MSW collection for a Local Authority?’ From a decision making perspective, this is the most crucial part. If the aim is not clear, the decision process is compromised from the very beginning causing confusion when trying to understand how drivers and barriers affect the decision making process.

4.3.1 Requirements

In terms of the requirements of the solution alternatives they are as follows. They must:

- Be in line with legislation – Any alternative considered must comply with EU legislation and subsequent UK and/or Wales specific transpositions as outlined in Chapter 1.
- Be environmentally beneficial – The alternatives to be considered must have a positive impact (i.e. reduce CO_2 equivalent emissions). This must include the potential savings from diversion of waste from landfill with the outlay of emissions from all aspects of collection considered.
- Involve separate collection of recyclate – Any alternative that is to be considered must collect MSW in a manner that separately collects recyclate, residual and food waste. This includes using various types of commingled collections or a kerbside sort approach where the householder separates the recyclate rather than using a single receptacle.
- Be publically acceptable – As stated in Chapter 3, the general public must accept the decision as their participation will dictate the diversion rates. If they are not happy with the service provided, find it difficult to understand or find any other reason to not participate, the results will be severely affected.
- Differentiate the collection styles – There are many ways to collect residual, recyclate and food waste. There is also the consideration of green waste. Must all four types be undertaken? Can two of them be collected together? These questions are important, as this determines the types of vehicle used and, due to differing vehicle sizes, the routes that they can take.

4.3.2. Goals

The goals are not mandatory to the process. However, the ideal outcome would be one which is in line with Government's direction. Through the Welsh Government's 'Towards Zero Waste' (WAG 2009) document, the preference is for a KSS approach. Whilst it would be ideal for the case study Local Authority (LA) to have the same outcome, however, this is not mandatory.

4.3.3. Identification of the Alternatives

The alternatives are the approaches that will solve the problem. In a SWM scenario, these are the methods of collection. To identify the alternatives, it is relatively straightforward, as outlined in chapter 1. The three basic methods of collection are a mixed waste collection and recyclate collected separately either as one stream or through source segregation. The aim is to separate at least the four main streams of recyclate (metal, paper/card (referred to as paper), glass and plastic), food waste and minimise the amount of residual that ends in landfill. For the identification of alternatives to be used they must be more clearly defined. The first two methods are a commingled collection of recyclate (CC) and kerbside sort collection (KSS). The CC provides one receptacle for the householder where all the recyclate is placed and collected. The KSS requires the provision of two to four separate receptacles for at least paper, glass, plastic and metal to be placed in, and the collection operatives separate the four materials into 'pods' on the stillage vehicle.

Further to these two methods, are the considerations of variations in the 2-stream collection approach. This works in much the same way as commingled collection, however there is a second receptacle to collect and keep one stream separate from the others. Another 2-stream variation is where two receptacles are provided for the householder, but the streams are collected in pairs, an example of which is glass collected with metal and paper with plastic. All of these permutations also involve separate collections for food and residual waste.

A mixed waste collection (one bag collection (OBC)) involves placing all the waste into one bag and therefore recyclate is mixed with residual and food waste. It would subsequently pass through a dirty MRF. Although this may seem like an abnormal choice of waste collection in view of legislation, it must be included as a possibility.

When first deciding upon which alternatives were to be used, the following permutations were considered:

- Kerbside sort (KSS)
- Commingled (CC)
- 2-stream with Paper collected separately (2S – Paper)
- 2-stream with Plastic collected separately (2S – Plastic)
- 2-stream with Glass collected separately (2S – Glass)
- 2-stream with Metal collected separately (2S – Metal)
- 2-stream with Paper and Glass collected together and Metal and Plastic together (2S – Pa/G & Pl/M)
- 2-stream with Paper and Metal collected together and Glass and Plastic together (2S – Pa/M & Gl/Pl)
- 2-stream with Paper and Plastic collected together and Metal and Glass together (2S – Pa/Pl & M/Gl)
- One Bag collection (mixed waste collection) (OBC)

To decide upon which of these would be included in the research study, various people in differing job specifications within LAs, SWM facilities (Materials Recycling Facilities (MRF) operators and/or landfill operators) and Welsh Government were consulted through meetings. They were asked to specify which of the above alternatives they would *not specifically avoid* and may practicably be considered. For waste management facilities, it was felt that if they were asked which they would use, only one or two alternatives would be selected. The results are shown in Table 4.1, where the separate colours highlight the four types of stakeholder. The advantage in asking various stakeholders in SWM is so that the choice of alternatives cannot be skewed by external factors.

Table 4.1 – Preferred methods of MSW collection with colour differentiation between types of stakeholder

Voter	One Bag	CC	KSS	2S - Paper	2S - Plastic	2S - Glass	2S - Metal	2S - Pa/M & G/Pl	2S - Pa/Pl & M/G	2S - Pa/G & Pl/M
LA #1										
LA #2										
LA #3										
LA #4										
LA #5										
WM facility #1										
WM facility #2										
WM facility #3										
WM Facility #4										
WG #1										
WG #2										
General Public #1										
General Public #2										
General Public #3										
General Public #4										

The results show all but two people were against collecting paper and glass being collected together and would never be considered in a two stream approach. The reason being that when glass breaks, it creates a large amount of contamination of the paper materials, which is very difficult to separate at any stage of post processing and would therefore be counterproductive. Otherwise, the two options that are most favoured are 2-stream with paper separate (unanimously) and 2-stream with glass separate collections.

The LAs preferences may be influenced by contractual agreements however they show a fairly similar pattern with the majority preferring most of the 2-stream approaches, CC and KSS. Welsh Government, in line with their *"Towards Zero Waste"*, has a focus on the source segregation and keeping as close to that as possible.

As a comparison, the question was also put to some members of the general public. Whilst the number used is not enough to state that it is reflective of the whole population, it does provide a guidance view. The general notion that the easier it is for the householder, the more likely they are to recycle, is reinforced (De Feo and De Gisi 2010).

However, preference is not the only matter for consideration and all methods of waste collection must be considered for analysis. Viewing the results, and because the following are widely accepted, the author decided to include:

- CC
- KSS
- 2-stream with paper separate
- 2-stream with plastic separate
- 2-stream with glass separate
- 2-stream with paper and metal collected together and glass and plastic together
- OBC

Although an OBC directly contravenes article 11 of the revised Waste Framework Directive (WFD) (2008) and this practise is no longer carried out across Wales as at 2014, it was included as it provides a baseline for comparison.

4.3.4. Development of the Evaluation Criteria

The best way to visualise the development of the evaluation criteria was through the use of a decision tree. This is a flow chart style of diagram that shows the user of the hierarchy of the decision process, such as in Figure 4.2. It starts with the goal at the top followed by the criteria and sub criteria through to the alternatives. By doing this, it is possible to break down the real world situation and more easily understand what is being studied. By focussing on and understanding each component in turn, eventually a sound global understanding of the decision making problem can be gained. In the following diagrams each layer represents the pairwise comparisons that need to be undertaken.

After the problem was defined and the alternatives selected, it was decided by the author, for easy identification that the layers of the hierarchy model wold be:

- First layer – ***Options***

- Second layer – ***Drivers and Barriers***
- Third layer – ***Operations***
- Fourth layer – ***Solution Alternatives***

These titles best represent the criteria or alternatives in these layers. They are colour coded to aid in identification of the different layers of the hierarchy. The second layer which is red, and labelled as ***Drivers & Barriers***, is one of the most important. It defines the decision making process in terms of understanding the choices the case study LA, or any user, makes

The criteria that are selected show how the user defines the problem. Particularly with a concentrated view to the drivers and barriers and how they respond to these. Firstly through the pairwise comparisons, the immediate importance of each criterion is identified. But the inclusion and exclusion of certain criteria also give an insight into the problem of selecting the most appropriate collection method.

The following diagrams of the hierarchy were created following many stages of consultation with the stakeholders as outlined previously in this chapter. The first problem to overcome was that of understanding what needed to be included at the beginning of the decision making process, to represent the solution to the main aim. Section 4.3.5 explains the boxes contained in Figure 4.2 which shows the first version of the hierarchical structure.

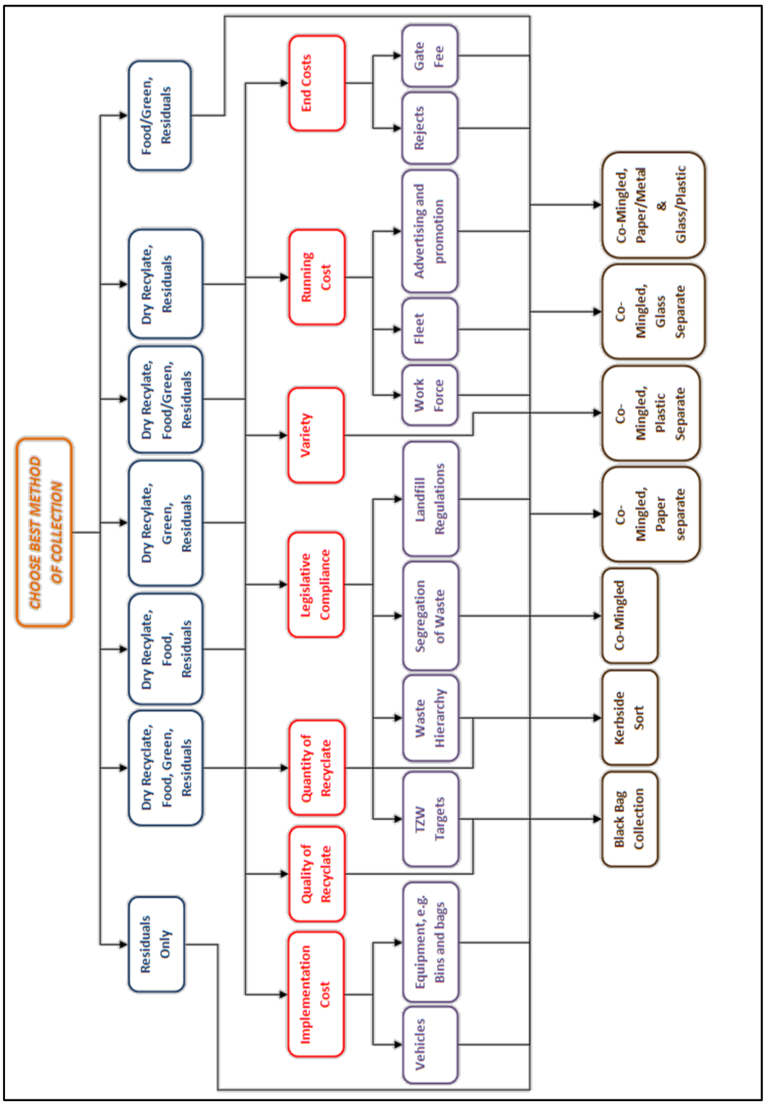


Figure 4.2 – The initial decision tree

4.3.5. Modules

In reference to the decision trees that are used to illustrate the decision making process in this chapter, the blue, red and purple boxes within these figures are called modules. A module represents a criterion that has pairwise comparisons undertaken of criteria in the layer below, with respect to it. The brown outlined boxes that are at the bottom of each diagram represent the solution alternatives, which feed in to other modules.

When the pairwise comparisons in a certain layer (or area thereof) are undertaken, the weighting assigned to each module is in relation to its 'parent' criterion. When multiplied by the weighting of the 'parent' criterion, this provides a global weighting i.e. the weight of that criterion, with respect to its parent criterion, with respect to the overall goal.

The best way to visualise this is to focus on one route through the decision tree. Firstly, in Figure 4.3, the 7 modules in the ***Options*** layer undertake pairwise comparisons, 21 in total, with respect to the overall goal. This will provide the global weightings for each module in the ***Options*** layer.

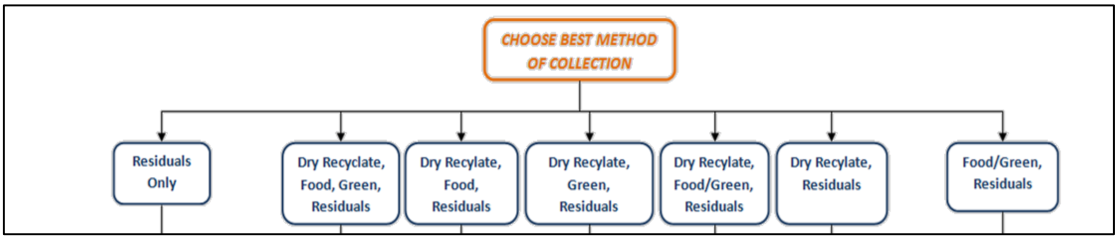


Figure 4.3 – Pairwise comparison for the 7 Options with respect to the overall problem

In Figure 4.4, the 7 drivers and barriers will form a matrix to create the 21 pairwise comparisons, with respect to the *'Dry Recyclate, Food, Green and Residual'* module. This will give a weighting for each of the 7 drivers and barriers (when summed, totalling 1.000) and when multiplied by the weighting of the *'Dry Recyclate, Food, Green and Residual'* module, a global weighting in relation to the overall problem is identified. The 21 pairwise comparisons of the ***Drivers & Barriers*** layer are then undertaken a further 6 times, with respect to the remaining 6 modules in the ***Options*** layer.

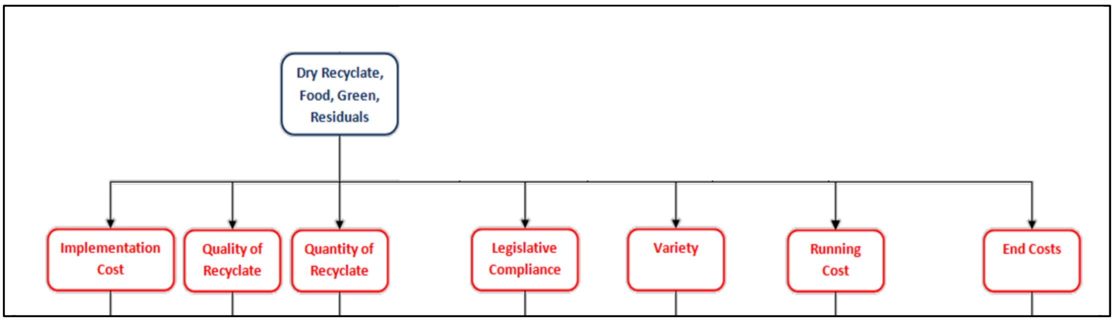


Figure 4.4 – Pairwise comparison for the 7 Drivers and Barriers with respect to the Dry Recyclate, Food, Green and Residual module

Next, focussing on the *'Running Cost'* module, pairwise comparisons must be undertaken between the criteria that it is 'parent' for. In Figure 4.5, the 3 criteria in the ***Operations*** layer, *'Work Force'*, *'Fleet'* and *'Advertising and Promotion'* are analysed through pairwise comparison. Again, their weightings must equal 1.000, and when multiplied by the global weighting of the *'Running Cost'* module, they will each be assigned a global weighting in relation to the overall goal.

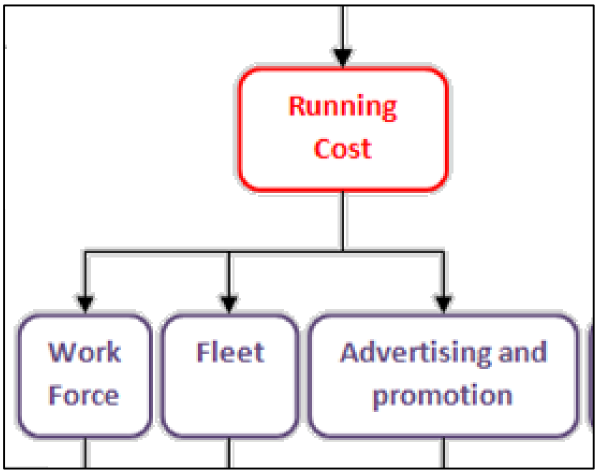


Figure 4.5 – Pairwise comparison for the 3 criteria under the 'Running Cost' module

In Figure 4.6, the focus is on the *'Work Force'* module. The 7 alternatives are compared in a pairwise manner against each other, in relation to the cost of the work force, in this instance. The weightings of the alternatives are multiplied by the global weighting of the parent criteria, giving the global weighting of the alternative, in relation to the overall problem defined. The modules in the ***Drivers & Barriers*** layer, that have no 'children' criteria in the ***Operations*** layer, will have a pairwise comparison of the alternatives in relation to them.

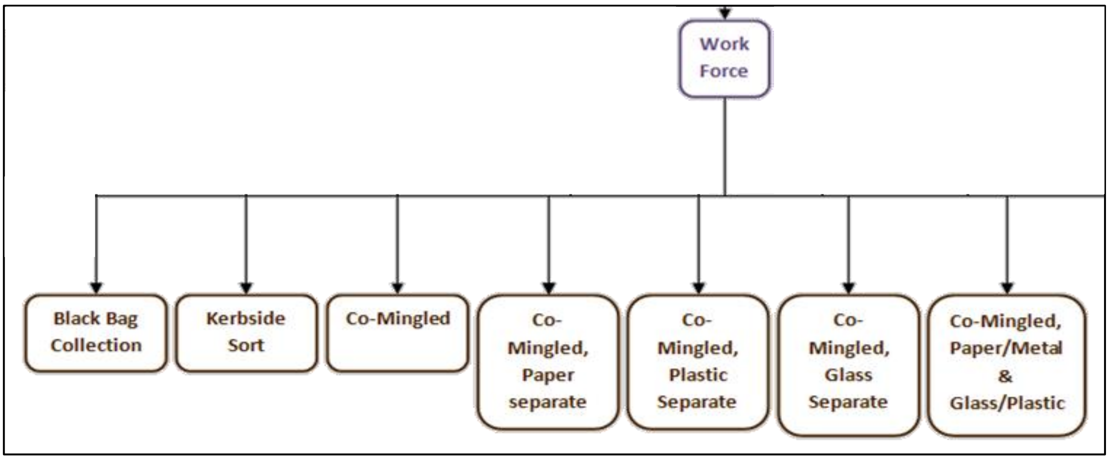


Figure 4.6 - Pairwise comparison of the alternatives with respect to the Work Force module

4.4 Decision of the Hierarchy

Following the many discussions with LAs over the first year of study, the author decided that for the collection of waste, the majority of emphasis is placed on how recyclate is collected. This opinion is backed up by the provision in Wales, of the Sustainable Waste Management Grant (SWMG). It is a grant provided by the Welsh Government for LAs, to aid in helping to achieve the 70% diversion of recyclate from landfill rate, set in 'Wise About Waste' policy document (WAG 2002), which is now a statutory target, by 2025 (Welsh Government 2010). Although food waste is also a major component of the decision making process, it will be dealt with separately and as a confirmation tool for the decision taken.

Owing to the nature of waste collection, the collection of food waste is somewhat dictated by the collection of recyclate. If KSS is used, then food waste will be collected by a pod on the stillage vehicle. If CC or any 2-stream approach is used, a LA will likely use a mixture of split body Refuse Collection Vehicles (RCV) and dedicated food collection vehicles. By carrying out a separate analysis of the food collection, it should concur with the choice of recyclate collection. In the event that the two results do not match up, this would count as new information being brought up and would cause the decision maker (DM) to go back, however many steps necessary, as per the decision making route map outlined in Figure 3.1, to re-evaluate. This provides a further method for checking consistency in making decisions, over and above that provided for in the AHP.

The ***Options*** layer shows the methods in which waste can be collected in general. This level of comparison uses the DMs experience and subjective views as to which option would be most preferable. The reason for allowing this stage to use qualitative data is mainly in the collection of green waste. As this is usually either carried out seasonally or as a pay-per-use service, it can greatly bias the decision if it were based on cost as a quantitative data input. The decision at this level could be based on previous data or which of the methods has proved most beneficial in the past.

The interconnection, and partial lack thereof, between the ***Options*** layer and the ***Drivers and Barriers*** layer shown in Figure 4.2 is a point of interest, due to two of the modules included here. The modules representing a *'Residuals Only'* collection and *'Food/Green and Residuals'* bypass the following two layers and lead in to a comparison of the solution alternatives directly. This is because they do not have the necessity of comparing the other criteria of collection, and thereby analysis, of recyclable material. In essence, there would be no need for comparison, as a black bag collection would be the only solution for *'Residuals Only'* and a two bag collection for *'Food/Green and Residuals'*. Although permissible in terms of the methodology, this was perceived as a weakness and was changed in due course.

The ***Drivers and Barriers*** layer was the most difficult to define. As pairwise comparison requires direct judgements between all criteria at this level, they must be comparable in terms of perceived importance to the DM. This is, again, a qualitative step. It may seem at first that cost, for the LA, is the main issue as they must work to budgets, but legislative compliance is manifestly important, as are other factors. It must be remembered that the decision making process must try to encompass all areas that are of most importance to the DM and not just monetary influence.

As can be seen in Figure 4.2, through consultation with three LAs in November 2012, the first seven criteria were chosen to initiate the study (Oakes and Keenan 2012; Greenhalf 2012; Wheeler 2012). Various costs of operation feature heavily in the form of *'Implementation Cost'*, *'Running Cost'* and *'End Cost'* modules. A measure of how well this service is carried out, includes how much of the target materials are collected and also, the quality of that recyclate. The more tonnage of recyclate that can be collected, it can be assumed that the collection is working effectively. Equally, the cleaner the recyclate is, the more likely it can be reprocessed rather than being incinerated thereby providing maximum environmental benefit, in line with 'Towards Zero Waste' (WAG 2009). Therefore the '*Quality of recyclate'* and *'Quantity of recyclate'* collected modules feature.

The *'Variety'* module signifies the number of different streams that can be collected by a Waste Collection Authority (WCA). As the LAs work to budgetary constraints, as any business entity does, it is clear why the analysis of cost of services provided is included. The variety of the number of streams that are collected can also be an indicator for performance of a collection system demonstrating the efficiency of the processors to react to market fluctuations. At this first checkpoint, these were the criteria agreed as being most pertinent overall, although entirely theory based at this stage.

The *'Legislative Compliance'* module represents the regulatory drivers and barriers placed upon the LA in collecting recyclate. Where there are targets to meet, alternatives which cannot be used or methods that should be followed, are represented in the decision making process by this module. Together, these seven modules are compared to each other via pairwise comparison, with respect to each of the modules in the ***Options*** layer.

The third layer represents the ***Operations*** of a waste collection and contains sub-criteria to the ***Drivers & Barriers*** layer. They are grouped according to their 'parent' criteria as shown in

Figure 4.7a-d. These comparisons are carried out as per their groupings i.e.:

- The cost of vehicles and equipment are compared with respect to *'Implementation Cost'* of a scheme
- The importance of Toward Zero Waste (TZW), The Waste Hierarchy, The Segregation of Waste (Regulation 13 of Waste (England and Wales) Regulations) and The Landfill Regulations are compared with respect to *'Legislative Compliance'*

- The cost of the work force, fleet and advertising costs are compared with respect to the *'Running Costs'*
- The cost of rejects and gate fees are compared with respect to the *'End Costs'* of waste

Again, LAs were approached to ascertain these sub criteria to reflect their considerations, in reference to the drivers and barriers they face.

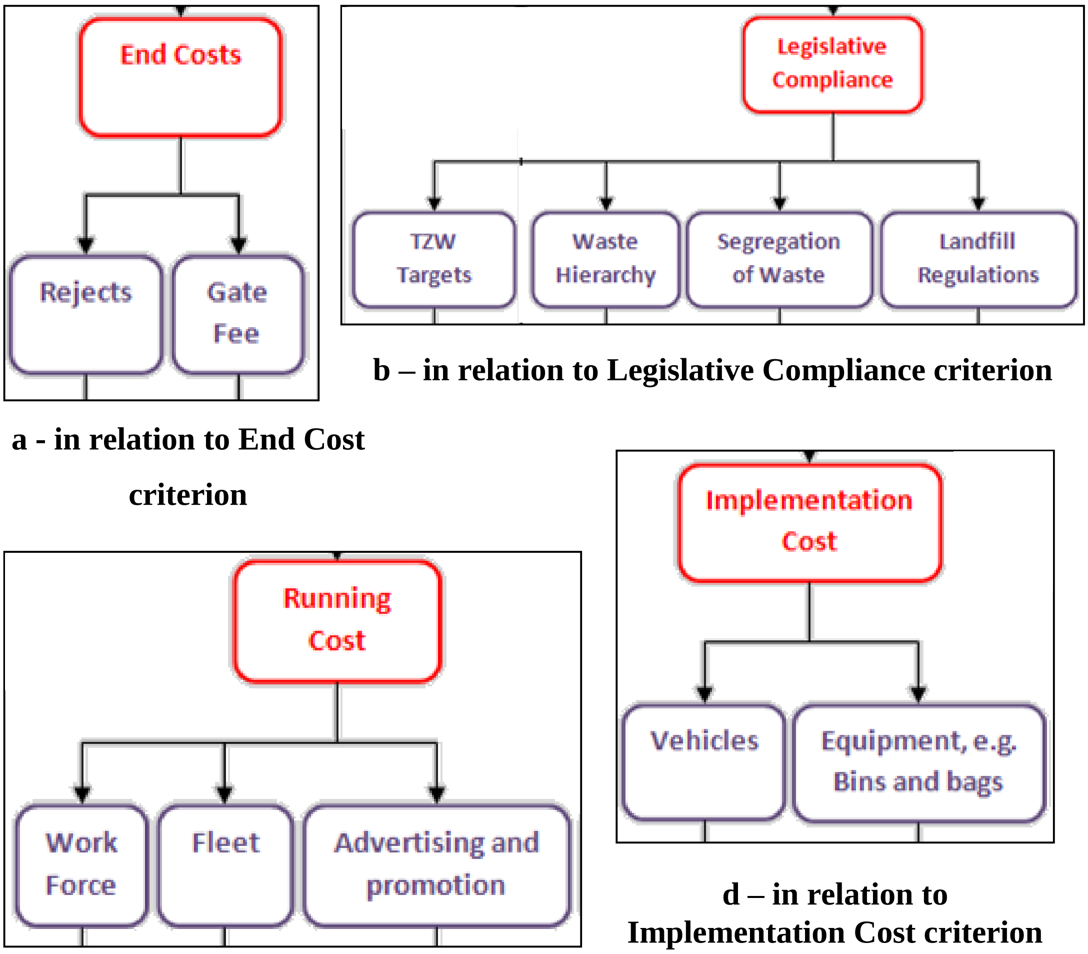
Once all of the above pairwise comparisons are carried out, the final round of decision making is of the ***Alternatives*** layer. A pairwise comparison of the solution alternatives with respect to the following modules would have to be undertaken:

- Vehicles
- Equipment
- TZW Targets
- Waste Hierarchy
- Segregation of Waste
- Landfill Regulations
- Work Force
- Fleet
- Advertising and Promotion
- Rejects
- Gate Fee
- Quantity of Recyclate
- Quality of Recyclate
- Variety

4.5 Development of the DST in Excel

Once the hierarchy was set up, a computer program was created to carry out the methodology itself. The software used was Microsoft Excel with Visual Basic Access, on account of its ease of use, flexibility and ability to create a user friendly interface. Excel is also widely used, creating a familiarity for the user.

Before any development occurred, through a personal communication (Oakes 2012) it was thought that although the quality of the recyclate was important, it was not actually considered by the LA. At the time, the LA was collecting MSW from households via a commingled collection and held a contract with a MRF to process the collected recyclate. Therefore, it was assumed that the quality was not of importance to the LA, as the MRF could handle any contaminated recyclate. Consequently, before the creation of the DST, the *'Quality of Recyclate'* module was removed from Figure 4.2.



a - in relation to End Cost criterion

b – in relation to Legislative Compliance criterion

c – in relation to Running Cost criterion

d – in relation to Implementation Cost criterion

Figure 4.7 – Pairwise comparisons occurs between subcriteria

Matrices were created for the pairwise comparisons to be undertaken. This was a basic Excel document meaning that the user had to physically click through each tab and fill in the matrices. An example matrix is shown in **Error! Reference source not found.** for the ***Drivers & Barriers*** layer where the value of 1 is entered in to the diagonal of the matrix. These are the comparisons of criteria against themselves.

The basic functions were entered to carry out the AHP calculations and the pairwise comparisons are then carried out dependant on whether the value is based on subjective or objective data input. To reduce inconsistency, the bottom half of the matrix is composed of the reciprocals of the corresponding values. In **Error! Reference source not found.**, the comparison for *'End Market'* against *'Quantity of*

Recyclate' is in cell *D14*, and the reverse comparison is in cell *C15*, containing the equation:

Reverse comparison ➔ 1/D14 **(4.30)**

Following the methodology of the AHP, once the matrix is completed, the geometric mean is calculated by taking the n^{th} route of the product of the row. Therefore, it follows that the formula found in cell *K14* in **Error! Reference source not found.**, for the geometric mean (geomean) of *'End Market'* is:

Geomean ➔ (C14*D14*E14*F14*G14*H14*I14)^(1/7) **(4.31)**

The weighting is found through a simple division of the individual geometric means by their total sum. In **Error! Reference source not found.**, the sum of the geometric means is held in cell *K21*, therefore cell *M14* reads as:

Calculation of the weightings ➔ K14 / K21 **(4.32)**

As a quick form of confirmation that the calculations are correct across the whole vector, they are summed, and should equal 1, as shown in cell *M21*, in **Error! Reference source not found.**.

The consistency measures are the last to be calculated. For Aω, a multiplication of the eigenvector by the matrix, in Figure 4.8, to aid in the calculation of the principle eigenvector, cell *N14* reads:

Aω ➔ (C14*M14) + (D14*M15) + (E14*M16) + (F14*M17) + (G14*M18) + (H14*M19) + (I14*M20) **(4.33)**

For the calculation of *A*, the vector representation of the matrix, the division of Aω by ω is calculated. Therefore, *O14* contains the equation:

***A* ➔ N14 / M14** **(4.34)**

The approximation for λ_{max}, the principal eigenvector, is required to estimate the consistency of the decisions made. Following through matrix theory (Saaty 2002), where a matrix contains ones along its diagonal and is consistent, then small variations in the z_{mn} will keep the largest eigenvalue, λ_{max}, close to *n*, and the remaining eigenvalues close to zero. λ_{max} can be calculated as the geometric mean of the vector *A*. Therefore cell *O23* reads as:

λ_{max} ➔ **(O14*O15*O16*O17*O18*O19*O20) ^ (1/7)** **(4.35)**

The consistency index (CI) is calculated where small changes in the z_{ij} imply small changes in the λ_{max}. The deviation of λ_{max} from n is a measure of consistency. This is represented by the deviation formula found in cell *O25* in Figure 4.8:

$\frac{\lambda_{max}-n}{n-1}$ ➔ **(O23-7) / (7-1)** **(4.36)**

Finally, to calculate the Consistency Ratio (CR), the average Random Index (RI) and CI are used. Table 3.3 gives the values for the average RI, depending on the order matrix. Seeing as this is a matrix of order 7, cell *O28* in Figure 4.8 reads:

CR ➔ O25 / 1.32 **(4.37)**

The guideline provided (Saaty, 1980) is that if the CR value is below 0.10, then the decision made is generally accepted. In Figure 4.8, the value is 0.025 and is below the acceptable level.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
12															
13			a	b	c	d	e	f	g		Geomean		ω (weighting)	Aw	A
14		a	1	2	3	4	5	6	7		3.380		0.352	2.553	7.260
15		b	1/2	1	2	3	4	5	6		2.318		0.241	1.729	7.167
16		c	1/3	1/2	1	2	3	4	5		1.534		0.160	1.142	7.157
17	This version is first	d	1/4	1/3	1/2	1	2	3	4		1.000		0.104	0.746	7.166
18		e	1/5	1/4	1/3	1/2	1	2	3		0.652		0.068	0.486	7.163
19		f	1/6	1/5	1/4	1/3	1/2	1	2		0.431		0.045	0.322	7.170
20		g	1/7	1/6	1/5	1/4	1/3	1/2	1		0.296		0.031	0.224	7.284
21											9.612		1.000		
22															
23														λmax	7.195
24															
25														CI	0.033
26														(λmax -n/)(n-1)	
27															
28														CR	0.025
29														(CI/CI check)	
30															

Figure 4.8 – Consistency Calculations in the DST

This is repeated for every set of pairwise comparisons required. These are tabulated to give a result for the best method of collection with respect to the criteria and the solution alternatives selected.

Figure 4.9 shows a sample of possible results where all the matrices were filled, for example purposes. Cell *R14* shows the weighting given to the option *'Dry Recyclate, Food, Green, Residuals'* in the ***'Options'*** layer and cells *R13, T13, U13…AF13* represent the global weightings assigned to the respective modules in the ***'Drivers & Barriers'*** layer of the hierarchy. Firstly the value is retrieved from the appropriate sheet and if necessary, multiplied by another to give the global weighting, leading to one of the following operations:

Retrieval of value ➔ $\boldsymbol{'TabName'!\,CellRef}$ **(4.38)**

Retrieval of value ➔ $\boldsymbol{'TabName'!\,CellRef \; * \; CellRef}$ **(4.39)**

The global weighting is the weighting of a criteria or alternative in relation to the goal. When carrying out the pairwise comparisons, this gives a weighting with regards to the parent criteria. This value must be multiplied the weighting for the parent criteria to give its impact in the overall analysis. For example, for the *'Dry Recyclate, Food, Green, Residuals'* value, cell *R14* contains the operation:

Retrieval of value ➔ '1 - Methods'!*M16* **(4.40)**

And for the global weighting of *'Quantity of Recyclate'*:

Retrieval of value ➔ ('2 -Em-Q-I-R-L-V-Ec'!*M15*) * *R14* **(4.41)**

The numbers from the weightings given in the pairwise comparisons between *'End Market'* (Em), *'Quantity of Recyclate'* (Q), *'Implementation Cost'* (I), *'Variety'* (V), *'Legislative Compliance'* (L), *'Running Cost'* (R) *and 'End Cost* (Ec)*'* are 0.352, 0.241, 0.160, 0.104, 0.068, 0.045, 0.031 respectively, as per **Error! Reference source not found.**. The weighting for *'Dry Recyclate, Food, Green, Residuals'* is (0.350). This is reflected in the values in cells *R13* to *AF13* in Figure 4.9 of 0.1230, 0.0844, 0.0558, 0.0108, 0.0237, 0.0364, 0.0157. This signifies that *'End Market'*, with respect to *'Dry Recyclate, Food, Green, Residuals'* has a global weighting of 12.3%. Therefore, in this case, it has been decided that the end market opportunities will have a relatively large influence on the decision compared to the end costs which only have a weighting of about 1.6%.

Similar actions are performed for the remainder of the table as shown in Figure 4.9, multiplying the weightings from pairwise comparisons at the ***Operations*** layer by those of the ***Drivers & Barriers*** layer and the ***Alternative'*** layer by the ***Operations*** or ***Drivers & Barriers*** layer.

Once all values are entered into the table, the values in rows 5 to 11 represent the global weightings of the solution alternatives, with respect to all criteria through the hierarchy. Therefore, to obtain the final weighting of importance for each of the alternatives, the program sums the values along the rows. Figure 4.10 shows the table used to represent these and cells *DK5* to *DK11* each contain the following formulae, where # represents the number of the row, as highlighted in Equation 4.14:

Check value for weightings ➔ SUM (B#:DI#) (4.42)

These weightings should add up to 1 and if they did not, there would be a mistake somewhere in the final results table. Figure 4.10 shows this not to be the case, due to cell *DK14* showing a value of 1.000. The weightings give the best suggested alternative, based on the judgements made. The higher the value of the weighting, the more *preferential* the alternative. It is important to remember that the methodology gives the best *suggested* alternative with regards to the criteria and alternatives chosen and not a definitive choice. The impact of this can be large when two alternatives that divide opinion, result in similar weightings. On the other hand, if one can be chosen with very good reason, then the decision can easily be made.

In Figure 4.10, the example shows KSS offered as the most favoured alternative with a value of 0.268. However, a Residuals Only collection has a weighting of 0.245 which is very close to the value assigned to KSS. These two are far ahead of the next best performing alternative, a commingled collection with paper separate at 0.122.

With two options so closely weighted, it is at the discretion of the decision maker(s) to decide which alternative best suits their needs. In this case, the choice is an obvious one. The Residuals Only collection does not meet with legislative restraints, especially with regards to the separate collection of recyclate (Article 11 of the WFD and Regulation 13 of the Landfill (England and Wales) Regulations 2011) and will most likely be disregarded, creating a clear favourite in KSS.

Figure 4.9 – Sample of the tabulated results of the matrices created through pairwise comparison

	A	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
1																	
2		Dry recyclate, Food, Green, Residuals															
3		End Market		Quantity	Implementation Cost		Variety	Legislative Compliance				Running Cost				End Costs	
4		Marketable Pr.	Transport		Vehicles	Equipment		TZW	W. Hier.	Segrag.	L. Regs	Contract	Work Force	Fleet	Adv & Prom	Rejects	Gate Fee
5	Residuals Only	0.0014	0.0003	0.0297	0.0178	0.0036	0.0041	0.0042	0.0025	0.0015	0.0009	0.0013	0.0065	0.0039	0.0022	0.0020	0.0040
6	Kerbside Sort	0.0320	0.0080	0.0203	0.0109	0.0022	0.0025	0.0026	0.0015	0.0009	0.0005	0.0008	0.0040	0.0024	0.0014	0.0012	0.0024
7	Co-Mingled	0.0037	0.0009	0.0135	0.0072	0.0014	0.0017	0.0017	0.0010	0.0006	0.0003	0.0005	0.0026	0.0016	0.0009	0.0008	0.0016
8	Co-Mingled - Paper	0.0170	0.0042	0.0088	0.0042	0.0008	0.0010	0.0010	0.0006	0.0003	0.0002	0.0003	0.0015	0.0009	0.0005	0.0005	0.0009
9	Co-mingled - Plastic	0.0062	0.0015	0.0057	0.0031	0.0006	0.0007	0.0007	0.0004	0.0002	0.0001	0.0002	0.0011	0.0007	0.0004	0.0003	0.0007
10	Co-Mingled - Glass	0.0092	0.0023	0.0038	0.0020	0.0004	0.0005	0.0005	0.0003	0.0002	0.0001	0.0002	0.0007	0.0004	0.0003	0.0002	0.0005
11	Co-Mingled - Pa/M & G/Pl	0.0290	0.0072	0.0026	0.0014	0.0003	0.0003	0.0003	0.0002	0.0001	0.0001	0.0001	0.0005	0.0003	0.0002	0.0002	0.0003
12		0.0984	0.0246		0.0465	0.0093		0.0111	0.0066	0.0038	0.0023	0.0035	0.0170	0.0101	0.0058	0.0052	0.0105
13		0.1230		0.0844	0.0558		0.0108	0.0237				0.0364				0.0157	
14		0.3497															
15																	
16																	

	A	DE	DF	DG	DH	DI	DJ	DK	DL
1									
2									
3		Running Cost			End Costs				
4		Work Force	Fleet	Adv & Prom	Rejects	Gate Fee		Weightings for Alternatives	
5	Residuals Only	0.0006	0.0004	0.0002	0.0002	0.0004		0.245	
6	Kerbside Sort	0.0004	0.0002	0.0001	0.0001	0.0002		0.268	
7	Co-Mingled	0.0002	0.0001	0.0001	0.0001	0.0002		0.115	
8	Co-Mingled - Paper	0.0001	0.0001	0.0000	0.0000	0.0001		0.122	
9	Co-mingled - Plastic	0.0001	0.0001	0.0000	0.0000	0.0001		0.065	
10	Co-Mingled - Glass	0.0001	0.0000	0.0000	0.0000	0.0000		0.061	
11	Co-Mingled - Pa/M & G/Pl	0.0000	0.0000	0.0000	0.0000	0.0000		0.123	
12		0.0016	0.0009	0.0005	0.0005	0.0010			
13		0.0034			0.0015				
14								1.000	
15									
16									

Figure 4.10 – Calculation of the weightings for the Alternatives in the DST

4.6 Initial testing and Feedback – The Second Iteration

4.6.1. General Assumption

Once the tool was in a position to be checked, consultation with the Case Study Authority was carried out. This led to further assumptions than those initially outlined in section 4.2.2 that needed to be made. By focussing solely on recycling, it was found that under *'Legislative Compliance'*, the ***Operations*** layer could be streamlined. The *'Waste Hierarchy'* module, representing Regulation 12 of the Waste (England and Wales) Regulations (2011), suggests that waste should be managed through prevention and minimisation first, secondly through reuse and preparation for reuse before thirdly, using recycling. The purpose of this decision support tool is for a LA to understand what might be their best method of MSW recyclate, food and residual collection. For this reason waste minimisation and (preparation for) reuse were not part of the decision making process, thereby negating the need for *'The Waste Hierarchy'* module.

This automatically excludes the need to include consideration for reuse and minimisation. In reality, waste minimisation could affect the choice of alternative for MSW collection. Minimisation, in particular, can affect the decision of MSW collection. By reducing the frequency of residual waste collection it was believed that it will encourage minimisation through extended use of recyclate and food collections (Date 2014b; Moore 2014). However, it was assumed to have a negligible effect at this point.

The *'Segregation of Waste'* module was also assumed as a necessity and did not enter into the decision making process. This is supported with all of the LAs in Wales providing at least a basic level of segregation of waste in all collection methods, shown in Table 1.2. Therefore it did not enter in to the decision making process for LAs. Furthermore, in Wales since 2001 when the SWMG was first introduced, the decision for the LA is directed so that waste must be collected separately. Without the aid of the grant, the implementation of new MSW collection methods would be very costly and difficult. This is especially true since the economic downturn in 2008, where budgets for LAs have been continually cut (Callan et al. 2011). The *'Segregation of Waste'* module, representing Regulation 13 of the Waste (England and Wales) Regulations (2011) in the pairwise comparison process, could therefore be removed.

4.6.2. Assumptions in relation to the LA

The following two assumptions have the effect of changing the decision tree to streamline the decision and make it more applicable to the case study LA.

Having access to a dirty MRF can have a large impact on the decision, due to decreased levels of residual waste going to landfill and boosting recycling rates. A dirty MRF is one that draws out recyclate from residual waste as well as sorting a mixed recyclate stream. It is therefore necessary to assume whether the LA has the benefit of a dirty MRF or not, as it changes the meaning of the criteria.

If the authority has access to or a contract with a privately owned 'dirty' MRF, when a bag of residual waste is collected, it can be processed. Owing to this fact, when looking at the ***Options*** of collection, a change was needed. Instead of regarding a single bag collection as that of solely residuals, the thought process was altered to view it as all potentially recyclable materials in one receptacle. Hence the change from *'Residuals Only'* and *'Food/Green & Residuals'* to *'Materials Only'* and *'Food/Green & Materials'* respectively, as represented in Figure 4.11.

It was assumed that the LA would be using an external contractor to carry out the waste collection and subsequent disposal. The impact of this assumption is that many of the costs can be amalgamated and covered by one value. This simplifies the decision making process itself and avoids confusion in the entry of data.

The LA expressed the need to consider what costs would be borne through using a third party. A third party in this instance could be a Waste Collection Authority (WCA) collecting the MSW on behalf of the LA, a Waste Disposal Authority (WDA) who processes the recyclate ready to be sold for an income or both. Whichever service that an external contractor is used for, there will be a cost incurred by the LA. Hence, the inclusion of a *'Contract Costs'* module as part of the *'Running Costs'* module to account for this financial outlay during the decision making process. Again, these changes are all represented in Figure 4.11.

4.6.3. Effect of New Assumptions

These assumptions divert the focus towards recycling. Although recycling is the main aim of the research, the LAs have a wider remit therefore setting the assumptions, help direct focus on recycling. The testing revealed that this was the area with the most contention and the decision making process focusses mostly on recyclate collection and disposal. The assumptions streamline this idea and provide more direction to the stakeholders and the DST. They also show how external factors must change the course of a decision, for example, where access to a 'dirty' MRF is assumed. Without documenting this assumption, there is no reason to consider all LACW at kerbside as potential recyclate. By doing so, it allows the analysis to bring together all the criteria in the top layer effectively in the AHP process, rather than bypassing the analysis.

The same is true of accounting for third parties being involved in collection and disposal of the LACW. It allows the amalgamation of concerns over the disposal of recyclate that could divert focus from important criteria, which must be analysed in the collection LACW as a whole. The initial assumptions all hold true up to this point and the limitations are still relevant.

4.6.4 Extra Considerations

The question of what is done with recyclate after it is collected and sorted was raised. This created a module to cover the end market for post processing. How do the solution alternatives affect the product that will be sold on? It was also necessary to be compared with the costs of getting the materials to market; leading to the creation of *'End Market'* module and its relevant sub-criteria in Figure 4.11.

It was also discussed with the LAs that the participation of the public must be included. How the householders interact with the collection scheme will affect the decision making process for the LA. This could be viewed as a driver, a barrier or part of the cost perspective. The public's perception of a scheme will influence their level of involvement. Thus, if they are satisfied with the scheme supplied then they are more likely to participate, aiding in increasing the diversion levels. Alternatively, if they are unsatisfied with the scheme, participation can decrease and affect the rates for that particular authority.

At this point in time, November 2013, this could affect the cost to a LA. The more recyclate that is collected by the LA, the more cost effective the scheme is. Conversely, should the participation rate drop, then this will cost the LA as they will be sending vehicles round on routes that are collecting recyclate at levels lower than predicted. With this in mind, the routes are planned to be optimised, meaning that the vehicles are working most economically by being as full as possible, when finishing a certain route. This is done through predicting the weight of recyclate and residual waste that will be collected on a certain route. These routes through a county that collect from all of the target houses, are fine tuned to travel the least distance possible. If participation is low, the vehicles will collect less recyclate than expected, creating routes that could have been otherwise avoided and increasing the cost in running the service.

4.6.5 Clarity

Following on from the second version of the hierarchy, the model was reviewed once more to improve clarity, especially in relation to how the modules are perceived. Therefore, the first change was to the *'Variety'* module which provided an analysis for the number of different streams that could be gathered by the various methods of waste collection. The naming of this module caused confusion as to what exactly was inferred. It was changed to *'Number of Streams Collected'*. For further clarity, in the top corner of Figure 4.12, an explanation for what the word 'materials' means in the ***Options*** modules, was added.

The *'End Costs'* module has been changed, joined by the removal of its reliant pairwise comparison in the ***Operations*** layer. The original reason for the *'Rejects'* module was to represent the cost incurred of rejects from a MRF, if materials cannot be processed and must subsequently be sent to landfill. The *'Gate Fee'* module represented the cost of sending residual waste to landfill. After further meetings, it was revealed that to attain the targets set by Welsh Government, as well as adhering to the Waste Hierarchy, then residual waste would have to be passed through a 'dirty' MRF (Oakes 2014a; Anon 2014). The potential recyclate needs to be picked out of the mixed solid waste to reduce the amount of waste sent to landfill. The rejects from this process will be sent to landfill and the cost transferred into a gate fee. Consequently, any waste that is sent directly to landfill or after processing will all have a gate fee attached. For this reason, they were amalgamated, leading to Figure 4.12.

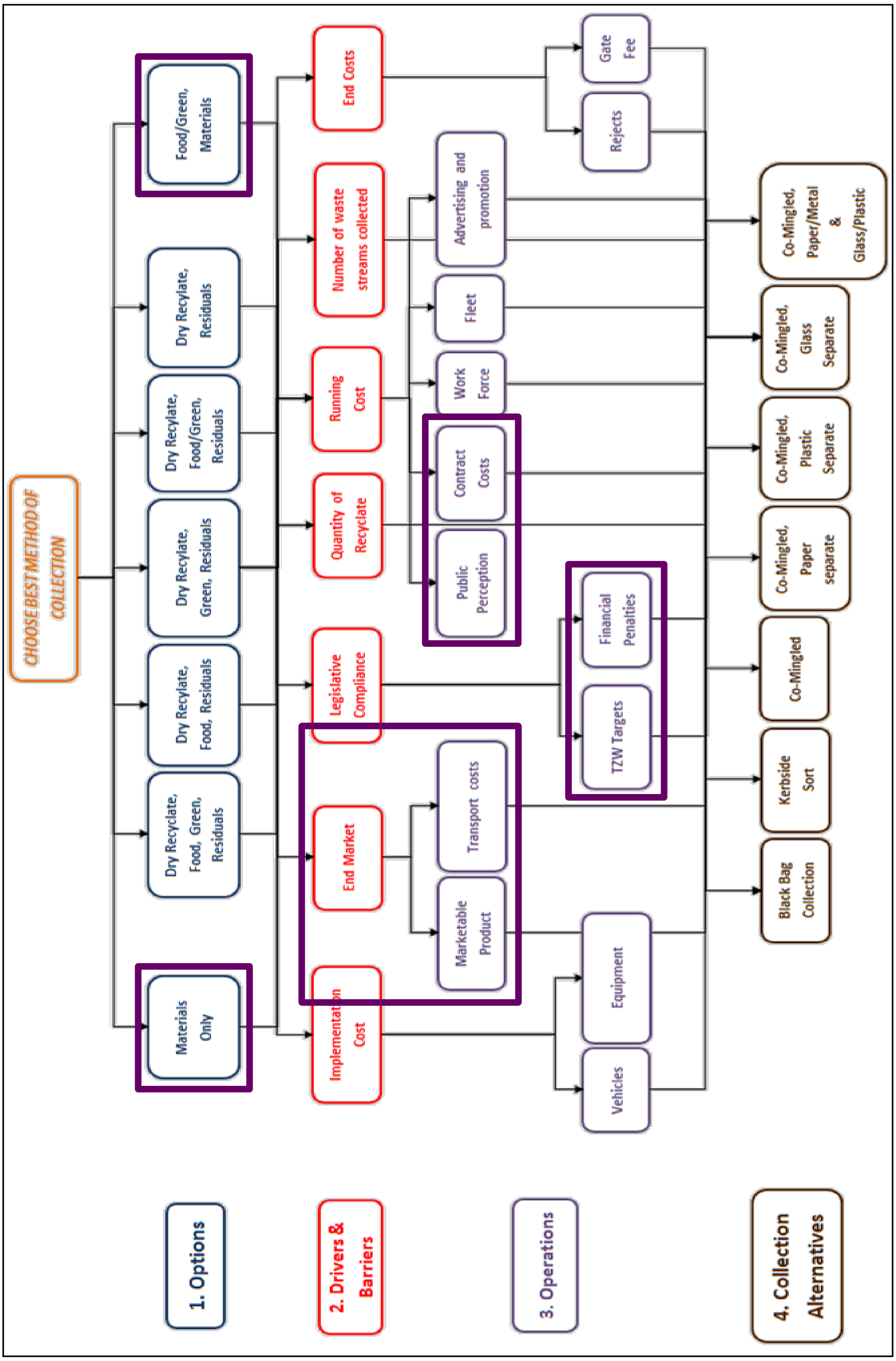


Figure 4.11 – Changes to the initial decision tree, highlighted by purple boxes

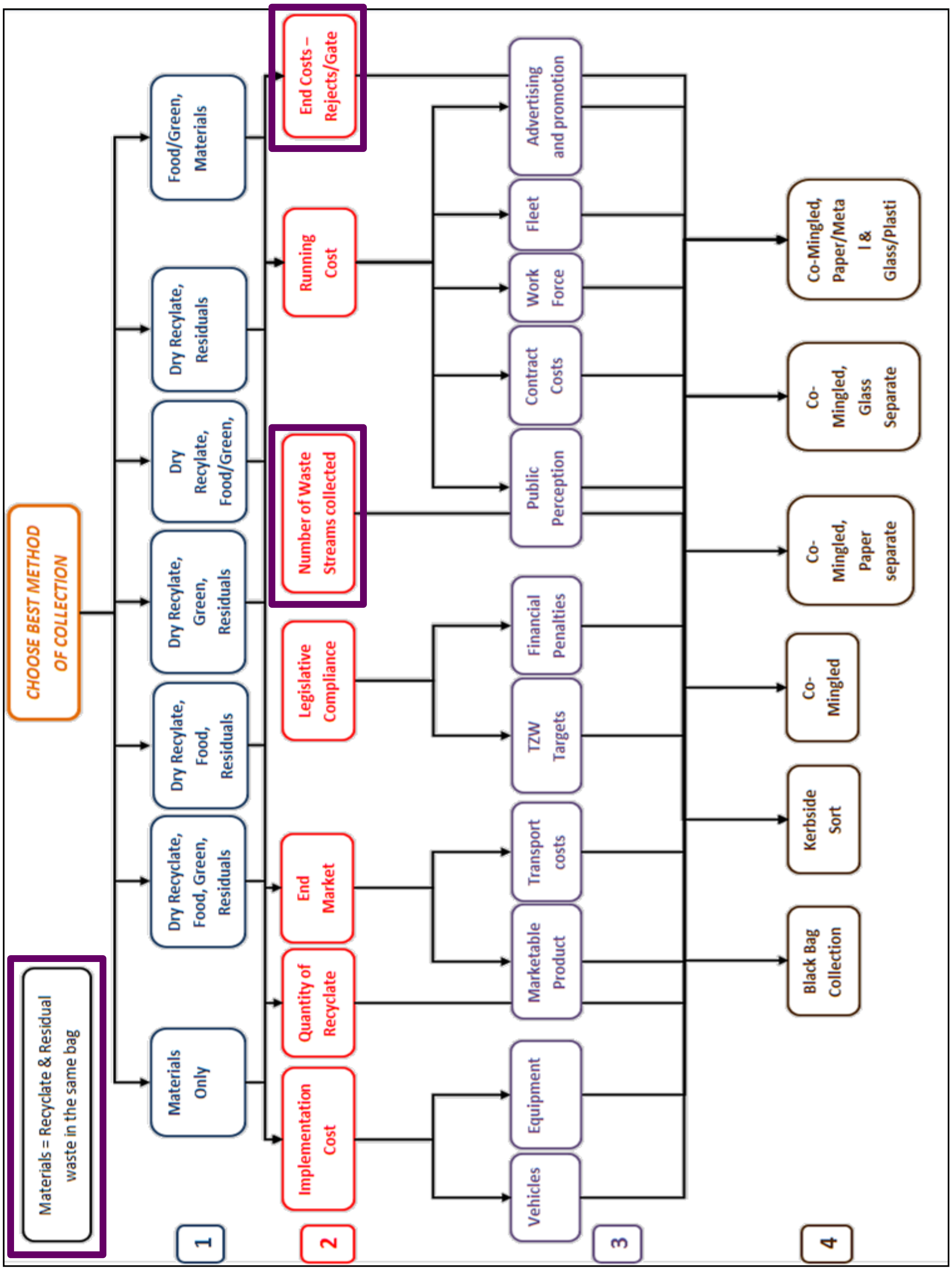


Figure 4.12 – Improvements for clarification of the Hierarchy (Third Iteration)

4.7 Testing

The DST was now at a stage where it could be tested. This was undertaken using qualitative data. The reason for this was that there is a large amount of data required with regards to a waste collection scheme, which was not yet collected by any of the LAs approached. The main aim of this test was to check whether the program accurately reflected the decision making process of the LA. The tool was taken to three LAs and a MRF operator to ascertain how well the tool reflected their decision making.

One of the most surprising outcomes revealed that the *'End Market'* module was viewed as being of negligible importance at this time. It was revealed that although it is considered, this is only the case in a casual way. It does not enter the formal decision making process when selecting a collection scheme. This is generally because the importance for the LA is to solely separate that which is required of them or they pass the responsibility on to a third party. This was not the case however for a MRF operator. As would be expected, for the enterprise to work, they must turn a profit. For this reason, MRF operators must be sensitive to market fluctuations and large scale changes (such as a new material having high demand). Due to the aim of the study being directed at LAs, the *'End Market'* module and its corresponding modules could be removed.

The *'End Costs'* module was reconsidered, in terms of its inclusion in the tool. The amount of recyclate and residual waste collected for each collection method is estimated by the LA. With a KSS approach, there are no rejects collected (in theory), and waste which ends up in landfill constitutes the gate fees. For a CC, a certain percentage is assumed to become rejects through a contractual agreement and converted into a cost. The cost would then be borne by the LA and can hence be projected and be considered as a net running cost instead. This brings the *'End Costs – Reject/Gate Fee'* module under the *'Running Cost'* module for pairwise comparison with other financial concerns, as *'Rejects'* module in Figure 4.13.

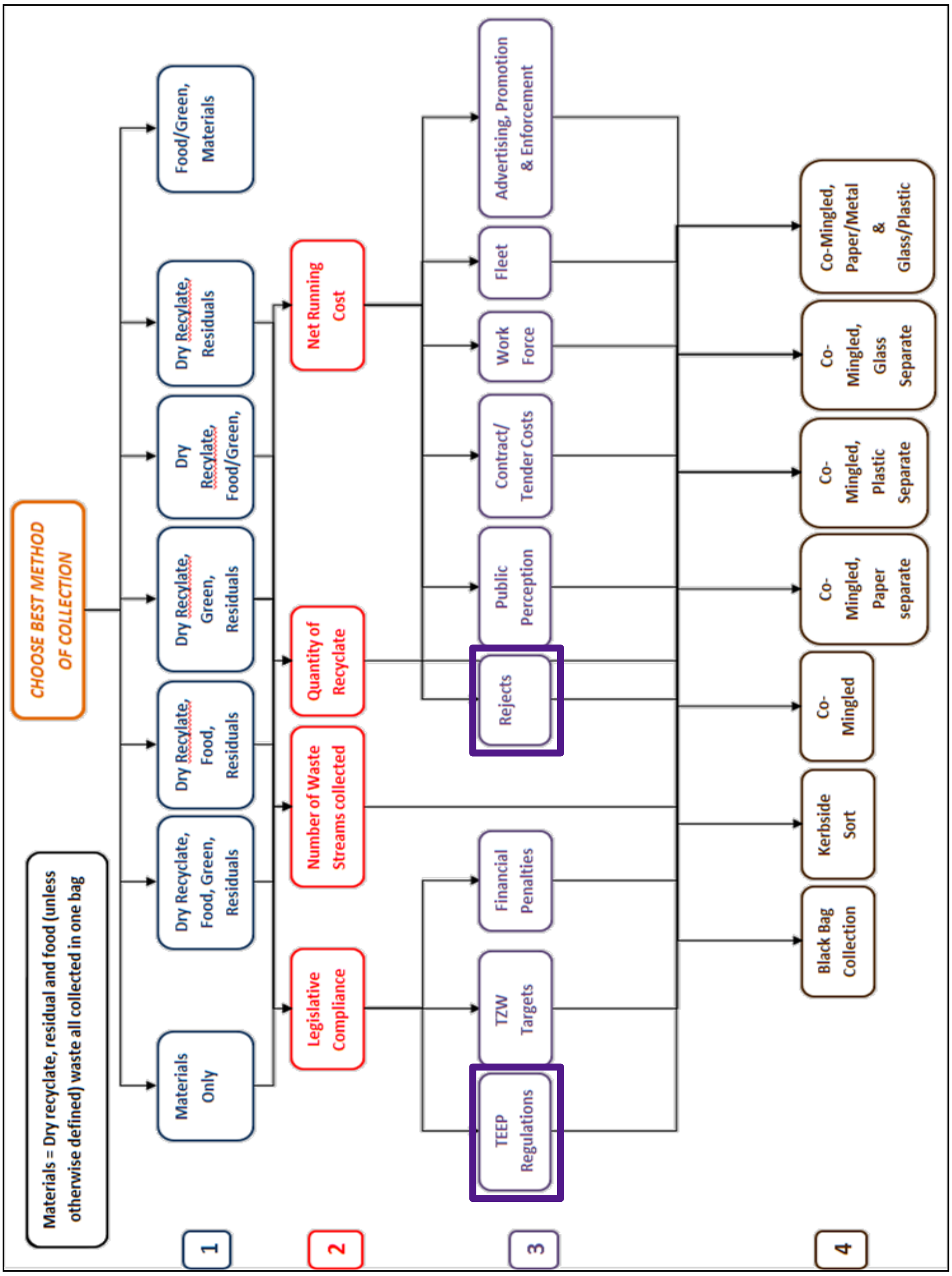


Figure 4.13 – Changes to the Hierarchy and DST, taking into account Environmental Consultants recommendations and after testing (Fourth Iteration)

4.8 Changes after testing and Recommendations of Environmental Consultants

Following on from testing, a few more changes were made to the hierarchy following notes made by the author during conversation with LAs. Meetings were also set up with two consultant companies that provide aid to LAs through analysis and research. The primary aim of these meetings was to provide an impartial view on the decision making process. As a result of all previous meetings and having to carry out an in depth explanation for the module titles, the secondary aim was to be able to show the hierarchy to anybody and they should be able to understand the meanings implied by their titles. Where this was not the case, an explanation would have to be provided as part of the DST. The changes put forward by the consultants are represented in Figure 4.14. Whilst these recommendations were very useful, they were not all implemented in the DST. Where they were used, the changes to the hierarchy in relation to the DST are shown in Figure 4.13.

4.8.1 Environmental Consultant Recommendations

When the environmental consultants were presented with the hierarchy, it was obvious to them that there was much collaboration with LAs. It is understandable that any LA approached, will focus mainly on the cost aspect of waste management, thanks to the strict budget that they must adhere to. These consultations with LAs, whilst necessary, also skewed the development of the decision support tool and methodology. There was a large emphasis on the various cost factors thus far. This is represented by four out of seven modules in the ***Drivers & Barriers*** layer evidenced in Figure 4.2, 4.16 and 4.17. Interestingly, up until this point, consultations with MRF operators, a landfill operator and the Environment Agency Wales (now Natural Resources Wales) did not highlight this skew in emphasis. When presented with the various versions of the hierarchy, they were mostly in agreement that these were indeed the main areas that they take into consideration for a MSW collection scheme.

It was thought that the bias in favour of cost could be reduced by merging these into one module, *'Net Running Cost'* in the ***Drivers & Barriers*** layer as per Figure 4.14. The running length of a collection scheme that a LA will operate is over a certain time period, generally four or five years before re-evaluation. This allows one off costs to be spread evenly over this time period. All initial costs can therefore be evaluated as a net running cost and be compared to other one-off costs as well as regular expenditures that have to be made throughout the life-span of a scheme, such as the work force expense.

Also, the end of the recycling process could be merged too. Whereas there were end market considerations and end costs of processing, their results are interlinked. This led to the suggestion of a module called *'End Market & Costs'* in Figure 4.14. It would consider the '*Gate fees'*, *'Marketable Product'* creation and *'Transportation Costs'* modules in pairwise comparison, under this new module.

Taking note of the suggestions, the first change was for the *'Running Cost'* module. Renamed as the *'Net Running Costs'* module in the ***Drivers & Barriers*** layer, its meaning was reformed slightly by Figure 4.13. The *'Contract Costs'* module was altered to include the consideration of tenders and their financial impact; thus creating a new title for this particular module of *'Contract/Tender Costs'*. This includes the procurement of equipment needed such as the three B's: bins, bags and boxes.

The consideration of the initial outlay of vehicles was also merged with the running cost of a fleet. The price and depreciation, if purchased rather than hired, would be factored across the lifespan of the scheme, allowing this merger. These modifications are seen in losing the *'Implementation Cost'* and associated modules in Figure 4.12 and a redefinition of what is represented by the *'Fleet'* module in the ***Operations*** layer in Figure 4.13.

The consultants believed that the Waste Hierarchy should also be included in the process. Although this is indicated in Figure 4.14, as stated earlier, it was decided that this would not feature in the program due to the focus on the recycling aspect. However, the *'Legislative Compliance'* module did gain another point of comparison in the evaluation of whether a scheme is technically, environmentally and economically practicable (TEEP).

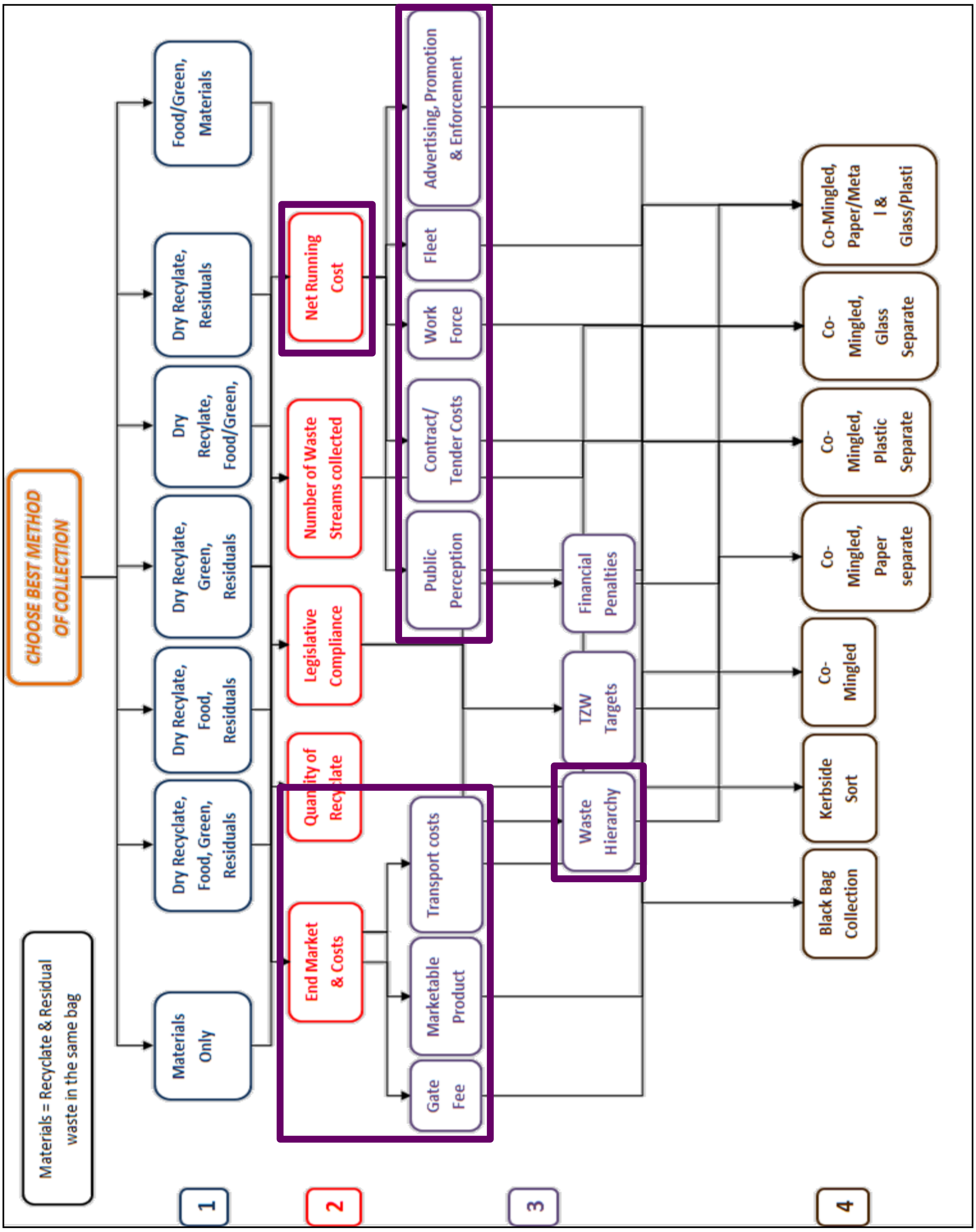


Figure 4.14 – The Hierarchy according to external Environmental Consultants

The *'TEEP Regulations'* module was introduced at the ***'Operations'*** level to allow for the consideration of Regulation 13 of the Waste Regulations. This states that any entity collecting paper, metal, plastic or glass must do so separately, and undertake recovery operations in accordance with Articles 4 and 13 of the WFD (2008) (in line with the

Waste Hierarchy and protecting human health and the environment) and complying with the TEEP ethos.

Article 11.2(a) of the WFD (2008/98/EC 2008) states:

> *'by 2020, the preparing for re-use and the recycling of waste materials such as at least paper, metal, plastic and glass from households…shall be increased to a minimum of overall 50% by weight…'*

This was transposed by the Waste Regulations where Regulation 13(1) states the same as above, ensuring the separate collection of the four main streams, but by 1st January 2015, so long as it is TEEP (The Waste (England and Wales) Regulations 2011). Regulation 13(2) provides more clarity on how this can be achieved:

> *'For the avoidance of doubt, co-mingled collection (being the collection together with each other but separately from other waste of waste streams intended for recycling with a view to subsequent separation by type and nature) is a form of separate collection'*

This Regulation explicitly allows any of the aforementioned methods of collections. However, the transposition and amendment of the Waste Regulations, in particular Regulation 13, was hotly contested and underwent a Judicial Review in 2013 (R(UK Recyclate Ltd & Others) v SSEFRA & Welsh Ministers, 2013). The issue was the wording and what was implied by practicable to separately collect the four main waste streams, where the claimants believed that a CC does not adhere to this. The judgement was that the transposition was clear and adhered to the WFD and allowed such a collection. Therefore, whether a collection is TEEP must be included in the decision making process and is much more important than previously thought.

Regulation 13 was subsequently amended in 2012 (The Waste (England and Wales) (Amendment) Regulations 2012) to change paragraph 2. They now read as:

> '(2) Subject to paragraph (4), an establishment or undertaking which collects waste paper, metal, plastic or glass must do so by way of separate collection.

> (3) Subject to paragraph (4), every waste collection authority must, when making arrangements for the collection of waste paper, metal, plastic or glass, ensure that those arrangements are by way of separate collection'

There is no longer any specific reference to what the meaning of separate collection exactly is in this paragraph of legislation. Welsh Government have deemed that the 'default' meaning for this, is a kerbside sort (KSS) collection. If a LA wishes to deviate from this, then they have to prove that a KSS collection is not TEEP and that a CC is. Therefore, Figure 4.13 reflects the absolute necessity to consider Regulation 13 of the Waste (England and Wales) Regulations 2011, with the inclusion of the *'TEEP Regulations'* module.

At this point it must also be noted, there was ongoing discussions of stakeholders in waste management, about the environmental benefits for diverting waste from landfill whilst limiting cost (Quayle 2014). The consideration of environmental factors however, has not yet figured in the hierarchy at all. This reveals much about the actual priorities of stakeholders when it comes to making the decision and where these are actually placed. Environmental impact is dealt with in legislation as a whole. The initial drivers for much of the European legislation including the WFD, and subsequently the Waste Regulations in the UK, are for the betterment of the environment. The assumption by LAs, and others in the industry, is that legislation forces beneficial environmental effects through waste management (Oakes 2014b). Could it be that the drive of higher targets in recycling, reducing the amount of waste to landfill and doing so in the cheapest possible way whilst maintaining high quality recyclate, removes the onus of environmental impact from LAs? At this point, yes. However, environmental impact is always in the peripheral vision of the LAs

Figure 4.14 shows the changes that would have been made by the external, impartial company. Whilst not included in the progression of the hierarchy with respect to the DST, it is clear by Figure 4.13, that elements as described above were incorporated.

4.8.2 Further assumptions

These changes reflect further assumptions that are made whilst testing the tool. Firstly, the heavy emphasis on the cost elements of a MSW collection scheme is assumed. Hence, the bringing together of all the cost criteria under one 'parent' module to limit the extreme effect of having many cost criteria may have.

Secondly, it is assumed that quality of recyclate is no longer of concern to the LA. The diversion away from considering quality in the process shows that the onus is no longer, at this time, on the LA. As stated in Section 4.6.2, the use of a 3rd party to carry out collection and disposal is the most likely reason for this shift in focus. So long as the third party accept the recyclate and can process it, there is no cause for concern to the LA. Also the environmental impact of a scheme is still assumed to have no direct influence on the decision made.

4.9 Fifth Iteration

4.9.1 Alterations to the Decision Tree

The fifth incarnation of the hierarchy is show in

Figure 4.15, where the user could decide what to include in their comparison. The overriding issue was that from month to month, various criteria are relevant to the decision making process for LAs. A good example of this is the quality of recyclate collected as a criterion for comparison. When the methodology was selected, it was thought to be important and necessary for inclusion. Upon revision in November 2013 after, quality of recyclate did not enter into the decision making process for a waste management collection scheme. Finally, by July 2014, it was a necessity to re-introduce it after continued governmental pressure. This mirrors the natural indecisiveness present in human decision making (Saaty 2000) and the inherent uncertainty in the future directions of waste management. This does not directly affect the nature of the hierarchy, but does affect how the program works.

Firstly, the changes that were made since the fourth iteration are considered. With the inclusion of the *'TEEP Regulations'* module featured as part of *'Legislative Compliance'*, the quality of the recyclate collected must be considered. If it were to be excluded from the decision making process, Regulation 13 of the Waste Regulations could not be adhered to. It could be argued that the quality of the recyclate could therefore be a legislative compliance consideration. The Sampling and Testing for Material Facilities (WRAP 2014) guidance states that by sampling input and output materials can improve quality of recyclate. However, there is no direct legislation giving a quantifiable measurement for quality. The author decided that the *'Quality of*

Recyclate' module be based on qualitative inputs and included in the ***Drivers & Barriers*** layer of the hierarchy.

After further consideration, supported by the literature studied (WAG 2009; De Feo and De Gisi 2010), public perception can play a large role in the decision making process for a LA, and may affect more than solely the cost standpoint. It is, in its essence, a driver for the LA if householders are accepting of the scheme or a barrier if not.

This highlights the difficulty of selecting criteria and at what level they must be at. One justification for the movement of this module is that the public's perception of any of the solution alternatives, could affect legislative compliance (as targets may not be achieved), quantity and/or quality of recyclate (through misuse of the scheme) as well as the net running costs. Due to its far reaching implications, it was more practical that the *'Public Perception'* module be moved up to the ***Driver & Barriers*** layer.

As mentioned previously, a considerable amount of emphasis was placed upon the environmental impact of any collection scheme and yet, it has not figured in the decision making process thus far. It also forms part of the debate over which of the alternatives performs best, and complies with legislation outlined, thereby impacting upon their suitability. With this in mind, the *'Environmental Benefit'* module was created under *'Legislative Compliance'*. This will be based on user judgements for the purpose of this study. In future, it could be used to incorporate LCA, should the LA and developer deem it necessary.

Towards the end of the process, changes were made to the ***Options*** layer. The modules in this layer no longer represented viable collection methods and did not aid in the decision making process. All LAs in Wales have moved towards an opt-in, paid collection of green waste, this is no longer a cause for concern in terms of general collection. It is agreed that to encourage further use of food and recyclate collection systems, they will be set as weekly collections.

Figure 4.15 shows the change of the ***Options*** layer and its comparison of the collection of residual waste on a weekly, fortnightly and three weekly bases. The fourth criterion studies the effect of not collecting glass as part of the kerbside collection. Instead, glass bring banks would be placed around the area and householders would take their glass to these. The WCA could then collect glass from these banks.

This re-introduces the use of collection frequency into the process. This invariably has a cost impact on the collection method. The less often you collect something such as residual waste, the cheaper it becomes. Assuming that the cost element is a major part of the decision process, this will invariably have an impact on the final outcome.

Also, the alternatives highlighted in Figure 4.15 have changed from previous iterations. Consultation with the case study LA led to these being the best alternatives. The alternatives must be specific to the entity undertaking the study, otherwise the analysis is pointless and these alternatives were viable options in their MSW collection. By including the *'Business as Usual'* alternative, the LA can compare what they are doing now, with future possibilities.

4.9.2 Food collection

As outlined in Section 4.3 food collection is used as a bottom up consistency check, so as to not ignore the impact of food collection. This is done using a less complicated, with less criteria and alternatives, form of AHP as shown in Figure 4.16. If the outcome of this AHP comparison shows that the pod on a stillage vehicle is the most preferred method of food collection, then one would expect to see KSS collection as the most preferred recyclate method of collection. Alternatively, if the dedicated vehicles and split body alternative proves strongest, then any form of commingled collection will be expected to be the strongest in recyclate collection. This effectively reflects the opinion of the LA, as quantitative data does not feature.

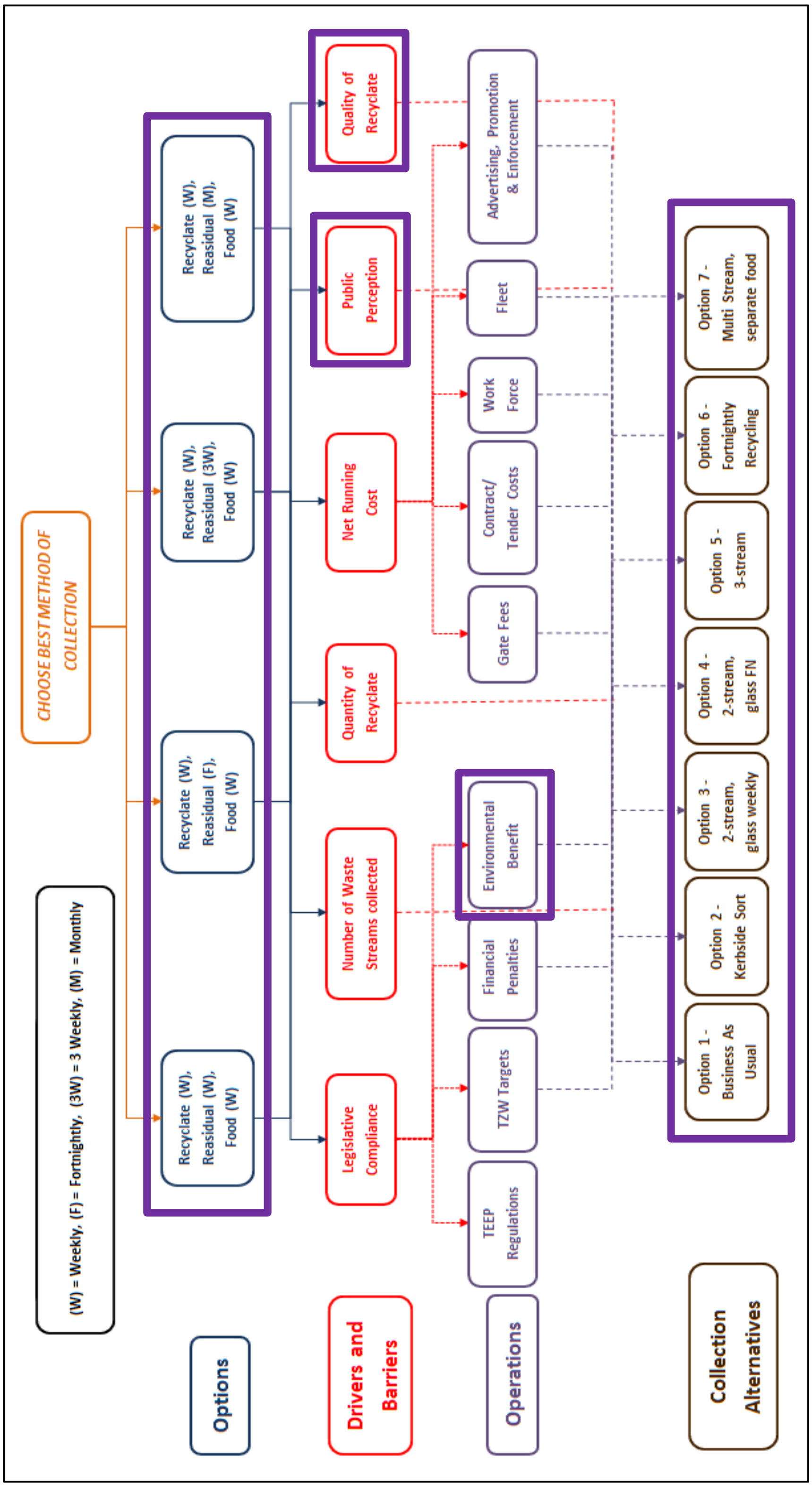

(W) = Weekly, (F) = Fortnightly, (3W) = 3 Weekly, (M) = Monthly
CHOOSE BEST METHOD OF COLLECTION
Options
Recyclate (W), Reasidual (W), Food (W)
Recyclate (W), Reasidual (F), Food (W)
Recyclate (W), Reasidual (3W), Food (W)
Recyclate (W), Reasidual (M), Food (W)
Drivers and Barriers
Legislative Compliance
Number of Waste Streams collected
Quantity of Recyclate
Net Running Cost
Public Perception
Quality of Recyclate
Operations
TEEP Regulations
TZW Targets
Financial Penalties
Environmental Benefit
Gate Fees
Contract/ Tender Costs
Work Force
Fleet
Advertising, Promotion & Enforcement
Collection Alternatives
Option 1 - Business As Usual
Option 2 - Kerbside Sort
Option 3 - 2-stream, glass weekly
Option 4 - 2-stream, glass FN
Option 5 - 3-stream
Option 6 - Fortnightly Recycling
Option 7 - Multi Stream, separate food

Figure 4.15 – Final Iteration of the Hierarchy

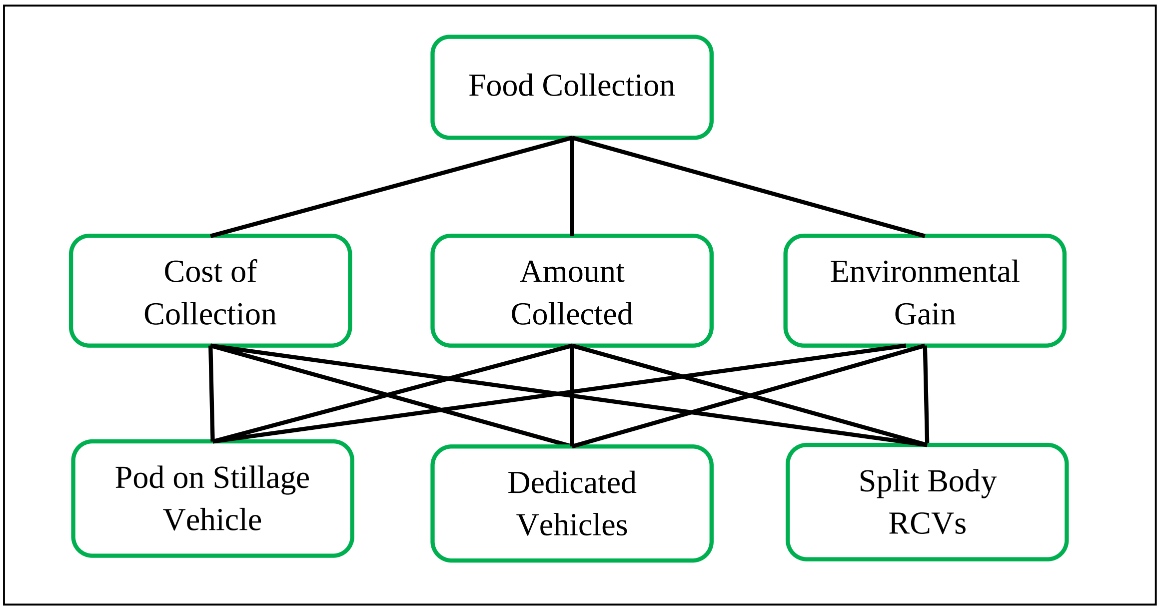


Figure 4.16 – Food Collection AHP as a 'bottom up' approach for testing the result

If the two results do not align then the decision maker(s) can reconsider previous decisions and review their results. This is in line with the explanation of the decision making route map, where any new information causes the decision maker(s) to revisit certain steps of the process. In this case, it could either be to re-evaluate the weightings or the inclusion/exclusion of any criteria, shown in the new process flow chart in Figure 4.17. The iterative steps if the two decisions, regarding food collection and recyclate collection, do not match up, are shown by red arrows indicating the previous steps that must be revisited.

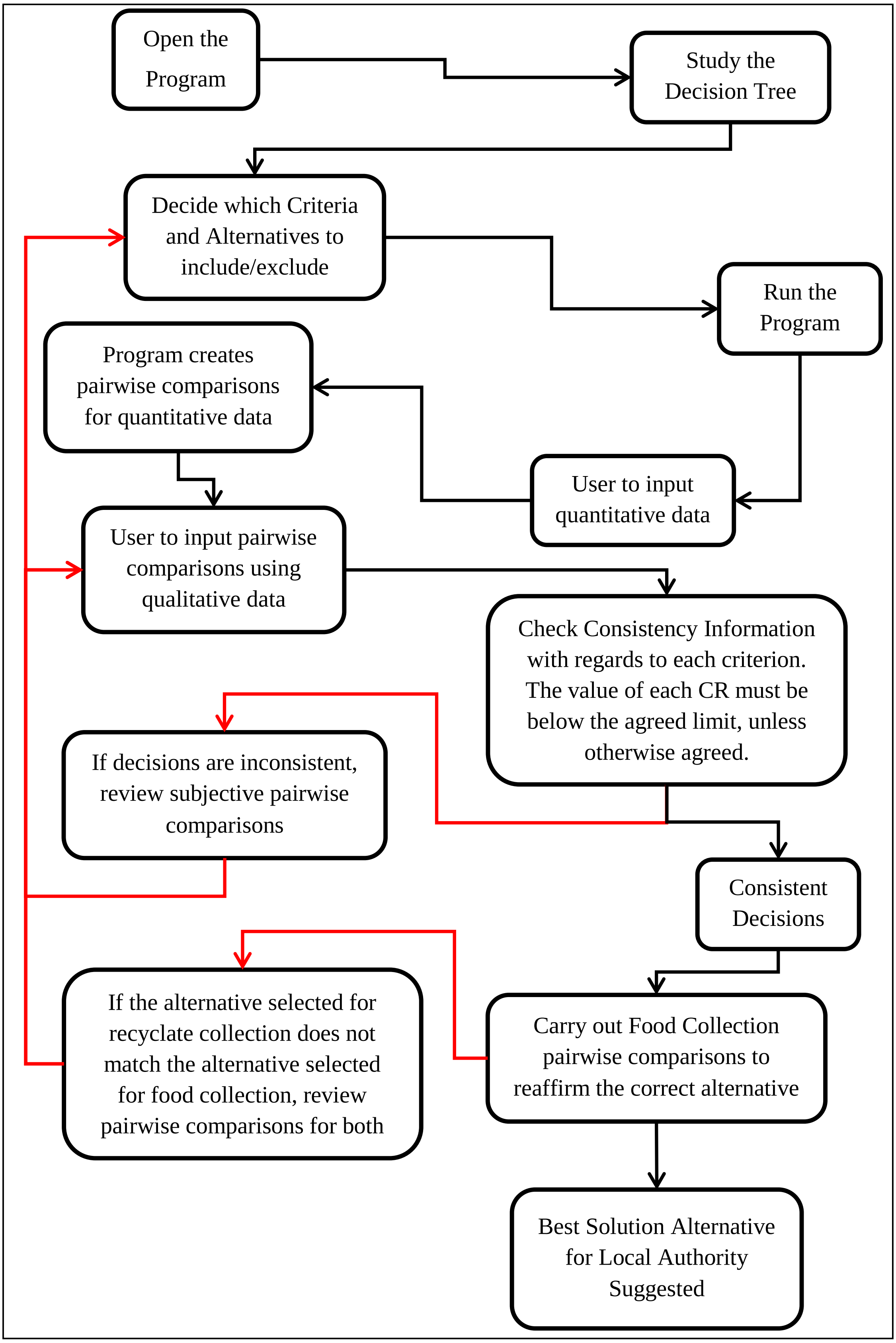


Figure 4.17 – Updated flow sheet including a consistency check with food collection

4.9.3 Final Assumptions

Following these final changes, the following assumptions were made:

- Food collection and recyclate should match – The alternative that performs best in terms of recyclate collection, will dictate to a certain degree the method of food collection. In reality, the two affect each other through cost and logistical considerations. However, it is easier in decision making to separate these two and carry out separate pairwise comparisons, for food and for recyclate. Therefore, one can be used to check the result of the other. If the results of these analyses match, then it can be most probable that the decision maker(s) have been consistent in their evaluation.
- Frequency is important and can be included – This addresses a limitation at the beginning of the process. Although frequency of collection is not included in full (i.e. that frequency of collection for recyclate, residual and food are all considered), it has been included. The decision to change the ***Options*** layer was to make sure the DST was relevant. Whilst under review, the combination of what could be collected was more important; however by the final iteration, it was generally agreed that recyclate and food must be collected on a weekly basis to achieve targets set. Therefore, it was more pertinent to investigate how the change in residual collection would affect the results.
- Quality is important – Throughout the study, quality of recyclate collected was a contentious issue. It was flagged as a necessary consideration in the beginning. As meetings progressed, it became apparent that quality did not present as an issue for consideration. Inevitably, as time progressed, quality of recyclate could not be ignored through legislative pressure by Welsh Government with respect to The Waste (England and Wales) Regulations (2011). The quality of the recyclate gathered ended up being included for consideration, but the results may show that it does not have a large impact.
- Environmental impact is considered – Similarly to the quality of the recyclate collected, the environmental impact is also included by the final iteration of the decision tree. The LAs deemed that it is a cause for concern but again, the results will show whether this has a small or large impact in their choice for MSW collection.

4.10 Creating versatility in the Program

Minor adjustments were made to the program to reflect the development of the hierarchy. It was not until the final modification of the hierarchy where major changes were made in terms of the calculation of the weightings, consistency checks and the input of quantitative and qualitative data. Extra changes were also made to give versatility to the user, allowing for the exclusion of criteria. An example of the final version is shown in Figure 4.18. There is a primary matrix, secondary matrix, calculation of the weightings from pairwise comparisons and subsequent consistency checks.

The comparisons are entered into the primary decision matrix through the pop-up forms and the program calculates everything else. The bottom matrix, termed the secondary matrix, allows the user to switch criteria (or solution alternatives) on and off, dependent upon if they are included in the pairwise comparison. At the same time, it is used for the calculation of *n*, the number of criteria.

4.10.1 Input methods

The input forms were also updated to reflect the changes in the general program. Examples of these are shown in Figure 4.19. The first is for the entering of data for the number of vehicles that would be used for any given collection method. The second is an example for the input of the pairwise comparisons. To avoid confusion, only the top half of the matrix is presented to the user. This allows them to enter the values they assign, as a comparison of those along the left of the matrix to those along the top, which will automatically transfer to the primary matrix and the corresponding reciprocal values.

	a	b	c	d	e	f	Geomean	ω (weighting)	Aω	A
a	1	2	3	4	5	6	2.994	0.381	2.344	6.158
b	1/2	1	2	3	4	5	1.979	0.252	1.534	6.099
c	1/3	1/2	1	2	3	4	1.260	0.160	0.977	6.101
d	1/4	1/3	1/2	1	2	3	0.794	0.101	0.616	6.104
e	1/5	1/4	1/3	1/2	1	2	0.505	0.064	0.392	6.101
f	1/6	1/5	1/4	1/3	1/2	1	0.334	0.042	0.262	6.170
							7.865	1.000		

λmax	6.122
CI (λmax -n/)(n-1)	0.02
CR (CI/RI)	0.020

1	1.00
2	1.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Move on to next tab

	a	b	c	d	e	f		
a	1	1	1	1	1	1	6	1
b	1	1	1	1	1	1	6	1
c	1	1	1	1	1	1	6	1
d	1	1	1	1	1	1	6	1
e	1	1	1	1	1	1	6	1
f	1	1	1	1	1	1	6	1
							n =	6

Figure 4.18 – An example of the primary and secondary matrices, calculation of weightings and consistency checks

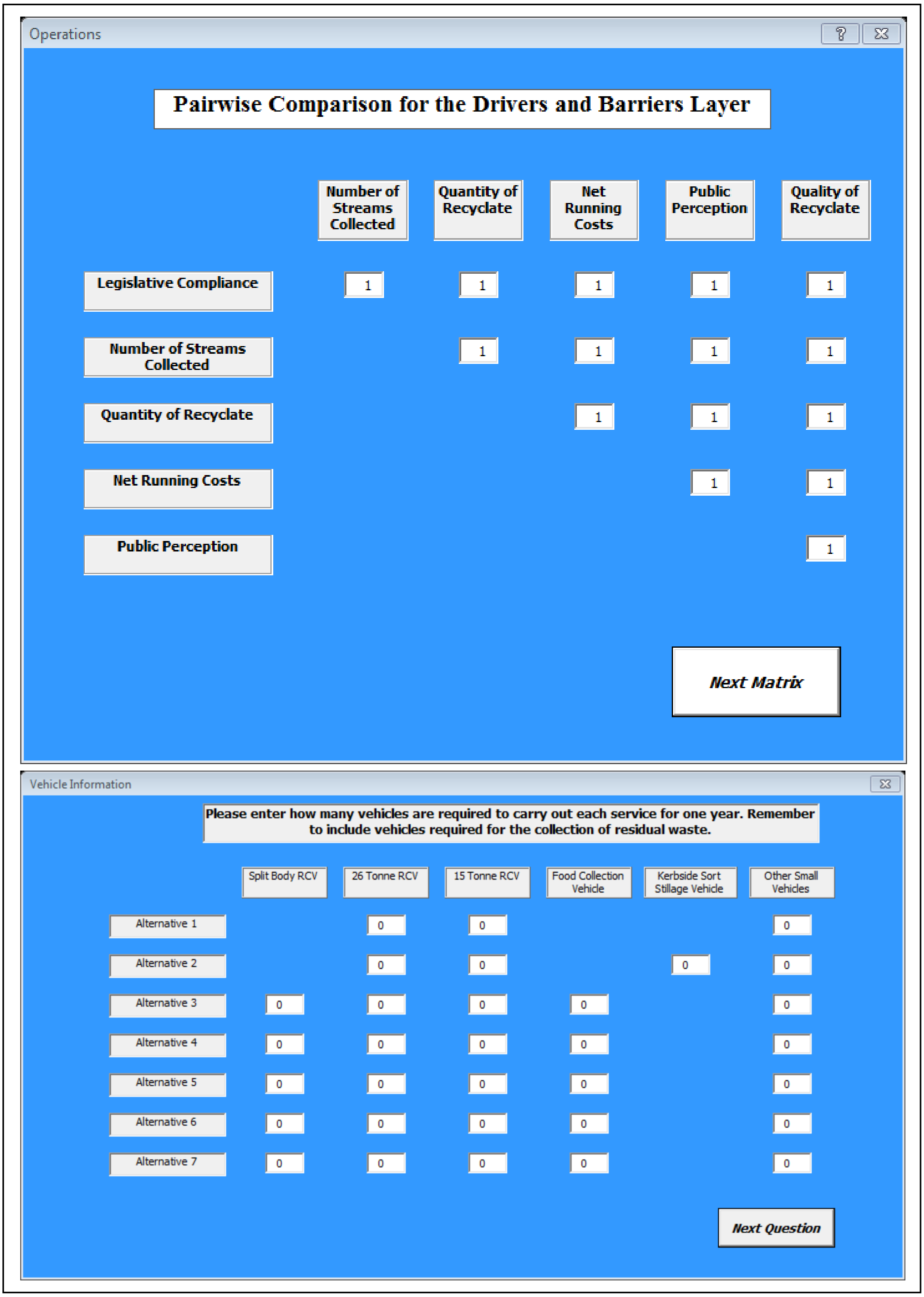


Figure 4.19 – Examples of the input forms for the final version of the DST

4.10.2 How values are entered into the Secondary matrix

The secondary matrix is a copy of the primary matrix with a slight difference. The secondary matrix values state whether the corresponding cell in the primary matrix, contains a 1 or any other value. In Figure 4.20, *D15* corresponds to *D33* (the comparison of (*a* , *b*)), *E15* to *E33* etc. If there is a 1 in the primary matrix, the value of 0 is assigned to the corresponding cell in the secondary matrix. If the value is anything but 1 in the primary matrix, the secondary matrix will assign the value of 1 to the corresponding cell. For example in Figure 4.20 the value of 4 in *H17* has a corresponding cell *H35* containing a 1. Note how the value in *E20*, the reverse decision, has also changed, thereby changing the corresponding value in the secondary matrix, in *E38*, to a 1.

The exception to this is the diagonal of the secondary matrix. These must always remain as a 1 for logic reasons, explained later in this chapter.

	a	b	c	d	e	f		Geomean
a	1	1	1	1	1	1		0.000
b	1	1	1	1	1	1		0.000
c	1	1	1	1	1	4		2.000
d	1	1	1	1	1	1		0.000
e	1	1	1	1	1	1		0.000
f	1	1	1/4	1	1	1		0.500
								2.500

Move on to next tab

	a	b	c	d	e	f		
a	1	0	0	0	0	0	1	0
b	0	1	0	0	0	0	1	0
c	0	0	1	0	0	1	2	1
d	0	0	0	1	0	0	1	0
e	0	0	0	0	1	0	1	0
f	0	0	1	0	0	1	2	1
							n =	2

Figure 4.20 – Proof of Secondary Matrix mechanism

4.10.3 The Sum Column

The column *I33:I39* is the 'sum column' of how many 1's are in each row of the secondary matrix. It signifies the number of values that have been allocated anything other than an equal weighting in the primary matrix, plus the 1 in the diagonal.

4.10.4 Calculating n using the Switch Column

To calculate *n*, one cannot use the value in the sum column. If any pairwise comparison is valued as equal (i.e. allocated a 1), Figure 4.21 shows the problem caused. Some of the values show the correct value for *n* as 6, however cells *I34* and *I38* show an incorrect value of 5 due to one equal comparison. Therefore, column *J33:J39* is required and is called the 'switch' column. Using an IF function:

Switch column ➔ $\boldsymbol{IF(CellRef > 1, 1, 0)}$ **(4.43)**

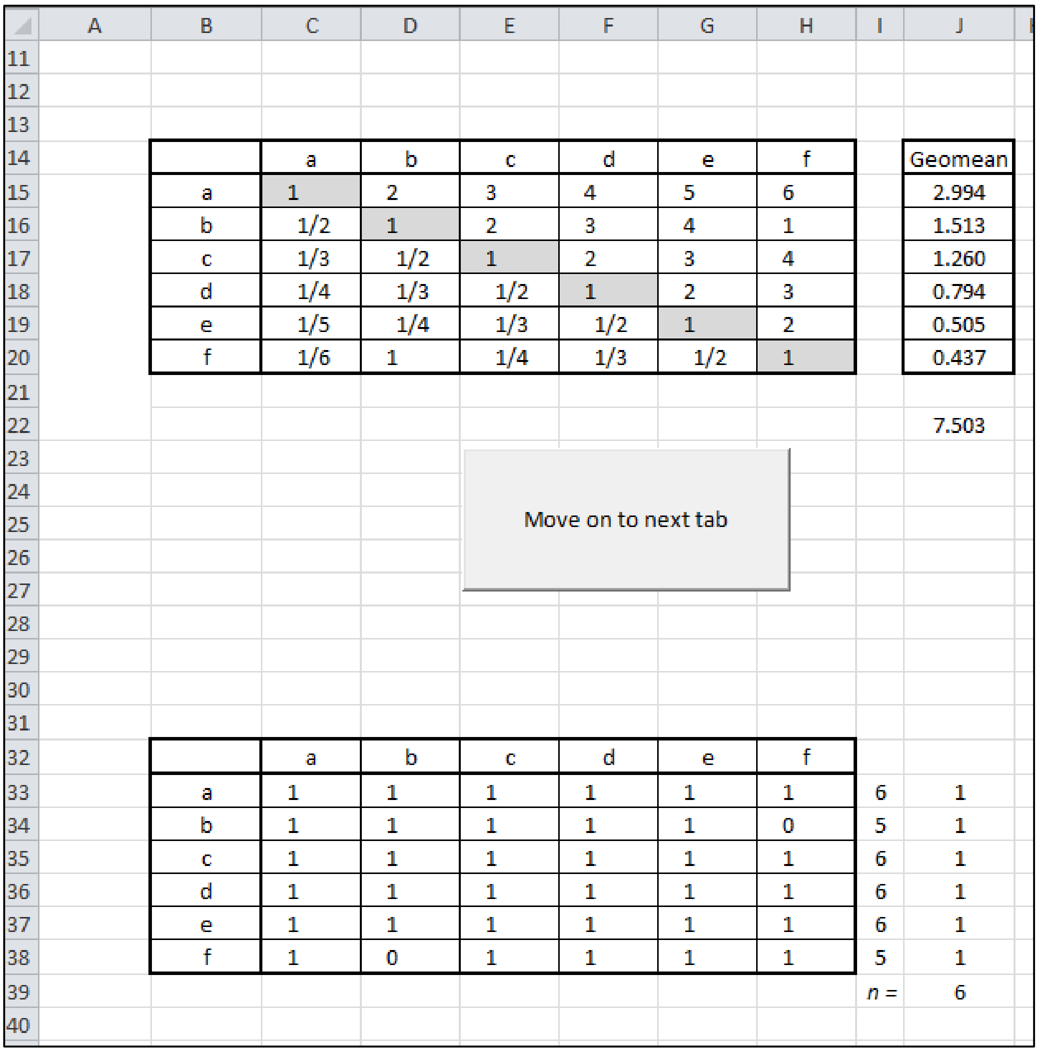
In cell *J33* ➔ $\boldsymbol{IF(I33 > 1, 1, 0)}$ **(4.44)**

It asks if the immediately previous cell has a value of 1 or not. Where the sum of the row is more than 1, assign a 1 in the switch column i.e. turn the criteria on. Where it is equal to 1, i.e. the only value in the row in the secondary matrix is the pairwise comparison that has been set ((*a*, *a*) , (*b*, *b*) etc.), assign a zero in the switch column. This negates any rows that are not wanted in the primary matrix.

For the calculation of *n*, a simple COUNTIF is required to ascertain whether there is a value of more than zero in the cells in column *J33:J38*. Any cell containing a 1, signifies that the criterion has been 'switched on'. Therefore the COUNTIF statement is as follows:

Calculation of *n* ➔ $\boldsymbol{COUNTIF(J33{:}J38, "> 0")}$ **(4.45)**

This means that for every cell that has a value greater than 0 in the range given, count and sum, giving *n*.



	a	b	c	d	e	f		Geomean
a	1	2	3	4	5	6		2.994
b	1/2	1	2	3	4	1		1.513
c	1/3	1/2	1	2	3	4		1.260
d	1/4	1/3	1/2	1	2	3		0.794
e	1/5	1/4	1/3	1/2	1	2		0.505
f	1/6	1	1/4	1/3	1/2	1		0.437
								7.503

	a	b	c	d	e	f		
a	1	1	1	1	1	1	6	1
b	1	1	1	1	1	0	5	1
c	1	1	1	1	1	1	6	1
d	1	1	1	1	1	1	6	1
e	1	1	1	1	1	1	6	1
f	1	0	1	1	1	1	5	1
							n =	6

Figure 4.21 – Discrepancy between value for *n* and sum of rows

It has the added benefit of being able to identify switched off criteria. The difficulty is understanding whether a 1 implies an actual pairwise comparison or an unwanted criterion. If, as per Figure 4.22, there is a row/column of 1s in the primary matrix, it is assumed that this is not to form part of the process and will assign 0s in the secondary matrix. The corresponding cell in the sum column (*I38* in Figure 4.22) will have a value of 1, meaning the user has decided to not include that particular criterion in the analysis. The 1 in the sum column represents the 1 in the diagonal of the matrix. It can therefore be ignored and 'switches' this row off by showing a 0 in the switch column. In Figure 4.22 criteria *f* is switched off as shown by 1s in its column, *H15:H20*, and row, *B20:H20*.

	a	b	c	d	e	f		Geomean
a	1	2	3	4	5	1		2.605
b	1/2	1	2	3	4	1		1.644
c	1/3	1/2	1	2	3	1		1.000
d	1/4	1/3	1/2	1	2	1		0.608
e	1/5	1/4	1/3	1/2	1	1		0.384
f	1	1	1	1	1	1		0.000
								6.241

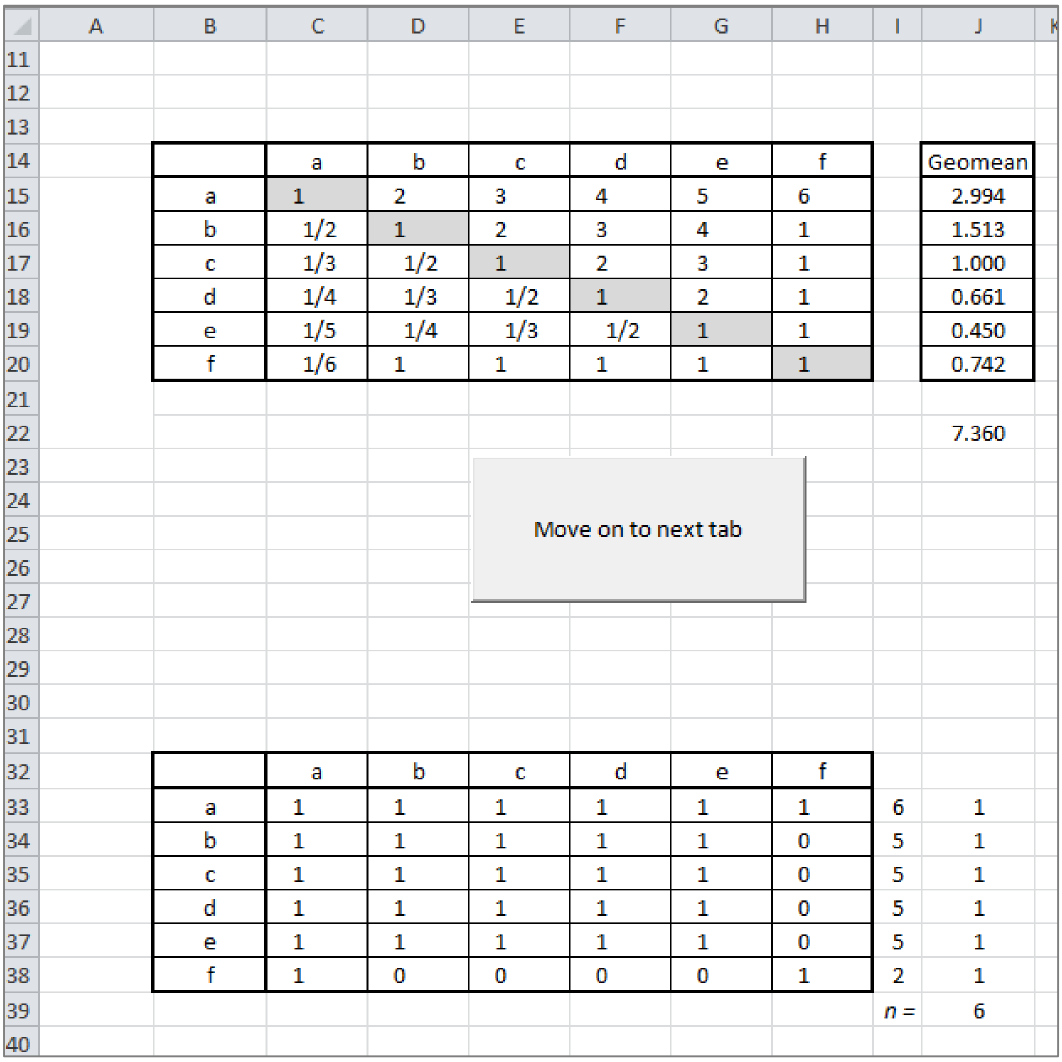
Move on to next tab

	a	b	c	d	e	f		
a	1	1	1	1	1	0	5	1
b	1	1	1	1	1	0	5	1
c	1	1	1	1	1	0	5	1
d	1	1	1	1	1	0	5	1
e	1	1	1	1	1	0	5	1
f	0	0	0	0	0	1	1	0
							n =	5

Figure 4.22 – Turning off one criterion with a row of 1s

4.10.5 How the matrices differentiate between switching off and a single comparison

There is the possibility that a criterion may enter the pairwise comparison, but have mostly equal weightings assigned. An example is shown in Figure 4.23. If criteria *f* was assessed to be equal with *b*, *c*, *d* and *e* then *n* still remains as 6 as there has been a comparison with *a*. Although in practice this would be considered as poor decision making, here it is for illustrative purposes. It can be seen that although criterion *f* is included in the pairwise comparison, many of the comparisons are assumed as equal. The sum column for *f* shows a 2, thereby keeping *f* switched on.



	a	b	c	d	e	f		Geomean
a	1	2	3	4	5	6		2.994
b	1/2	1	2	3	4	1		1.513
c	1/3	1/2	1	2	3	1		1.000
d	1/4	1/3	1/2	1	2	1		0.661
e	1/5	1/4	1/3	1/2	1	1		0.450
f	1/6	1	1	1	1	1		0.742
								7.360

	a	b	c	d	e	f		
a	1	1	1	1	1	1	6	1
b	1	1	1	1	1	0	5	1
c	1	1	1	1	1	0	5	1
d	1	1	1	1	1	0	5	1
e	1	1	1	1	1	0	5	1
f	1	0	0	0	0	1	2	1
							n =	6

Figure 4.23 – How the secondary matrix does not turn off the *f* criterion

4.10.6 Consistency Checking and the Secondary Matrix

Figure 4.24 shows a matrix with no weightings undertaken in the primary matrix, i.e. populated with 1s, to prove it turns the criteria off. This leads to there being a zero vector for the Geometric mean (column *J15:J20*) because the formula is:

Calculation of geomean ➔

$$\boldsymbol{IF(CellRef = 0, 0, (C\# * D\# * E\# * F\# * G\# * H\#)\hat{}(1/J39))} \quad \textbf{(4.46)}$$

$$\boldsymbol{IF(J33 = 0, 0, (C15 * D15 * E15 * F15 * G15 * H15)\hat{}(1/J39))} \quad \textbf{(4.47)}$$

Meaning if *J33* is a zero value (i.e. that no judgement has been passed on criterion *a*), the geomean will have a value of zero, to negate the overall criterion from being part of the process, likewise for each subsequent criterion. Otherwise, calculate the geometric mean from the pairwise decisions made, and use the value in *J39* for *n*.

For the calculation of the weighting in *L15:L20*, the following equation was used:

Calculation of weighting ➔ $\boldsymbol{IF(CellRef = 0, 0, CellRef/J22)}$ **(4.48)**

$$\boldsymbol{IF(J15 = 0, 0, J15/J22)} \quad \textbf{(4.49)}$$

This refers back to the geomean. If the geomean is a zero, then the criterion has been switched off and the weighting must be a zero so that it does not impact on those involved in the comparison. Otherwise, carry out the division of the geomean for criterion *a*, in equation 4.21, by the total sum of all the geomeans.

For the consistency checks, an *IF* function was used again, which referenced the weighting. Therefore, for criterion *a*:

Multiplication of the matrix by the weightings ➔

$$\boldsymbol{IF(L15 = 0, 0, (C15 * \$L\$15) + (D15 * \$L\$16) + (E15 * \$L\$17) + (F15 * \$L\$18) + (G15 * \$L\$19) + (H15 * \$L\$20))} \quad \textbf{(4.50)}$$

If the weighting is 0, then $A\omega$ will also equal 0. Otherwise, multiplication of the matrix by the weighting vector will occur. For the *A* vector, it is slightly different for cell *O15* the formula is:

Calculation of *A* ➔ $\boldsymbol{IF(L15 > 0, N15/L15, 1)}$ **(4.51)**

If the weighting is more than 0, then divide *N15* by *L15*, otherwise enter a 1. For λ_{max}, it is reliant on the value of *n*. If this value is at least 3, then λ_{max} will be calculated as taking the geometric mean of the values in *O15:O20*, otherwise a value of 0 will be entered. Shown by equation below:

$$\boldsymbol{\lambda_{max}} \text{ ➔ } \boldsymbol{IF(J39 > 2, (O15 * O16 * O17 * O18 * O19 * O20)\verb|^|(1/J39), 0)} \quad \textbf{(4.52)}$$

The Consistency Index check is then reliant upon λ_{max}. If the value of $\lambda_{max}$is 0, a 0 is entered into cell *O26*, otherwise the ratio of change between n and λ_{max} is calculated as per the following equation:

Consistency Index ➔ $\boldsymbol{IF(O24 = 0, 0, (O24 - J39)/(J39 - 1))}$ **(4.53)**

In AHP, the Consistency Ratio (CR) is calculated by dividing the Consistency Index (CI) by the Random Index (RI) as outlined by Saaty (1980). The table for the RI is included on every tab in the program for ease of reference. The equation in *O28* reads what the value for *n* is in cell *J39*. It then references the array (cells *Q12* to *R22*), find the matching number in the *Q* column and the corresponding value in the *R* column. The equation used in cell *O28* is:

Consistency Ratio ➔ $\boldsymbol{O26/VLOOKUP(J39, Q12{:}R22, 2)}$ **(4.54)**

4.10.7 No use of 0s in the primary matrix and in the A vector

It has been stated throughout this chapter that certain elements use 1 as a value where, for simplicity and understanding it may have been easier to use 0s. This section explains why this has not been the case.

The first issue to address is why 1s are used in the primary matrix. Figure 4.25 shows a fully functioning matrix and its associated calculations, with example numbers entered in to the primary matrix. The second part of Figure 4.25 shows what happens if 0s are used to switch off any of the criteria, *f* in this instance, and the effect it has in comparison to a matrix with comparisons entered. Through the use of multiplication to evaluate the geomean and weighting, a 0 in any cell within the primary matrix will cause a value of 0 to be entered in to the associated geomean or weighting cell. If used across a whole column (and by association a whole row), this leads to all values in the geomean column becoming 0s.

For further clarity, Figure 4.26 shows just one cell, *H17*, containing a 0, where this is the pairwise comparison (*c* , *f*). It has caused the weighting for both criteria involved to become 0 and therefore given negative values for CI and CR, which are not plausible.

	a	b	c	d	e	f	Geomean	ω (weighting)	Aω	A
a	1	1	1	1	1	1	0.000	0.000	0.000	1.000
b	1	1	1	1	1	1	0.000	0.000	0.000	1.000
c	1	1	1	1	1	1	0.000	0.000	0.000	1.000
d	1	1	1	1	1	1	0.000	0.000	0.000	1.000
e	1	1	1	1	1	1	0.000	0.000	0.000	1.000
f	1	1	1	1	1	1	0.000	0.000	0.000	1.000
							0.000	0.000		

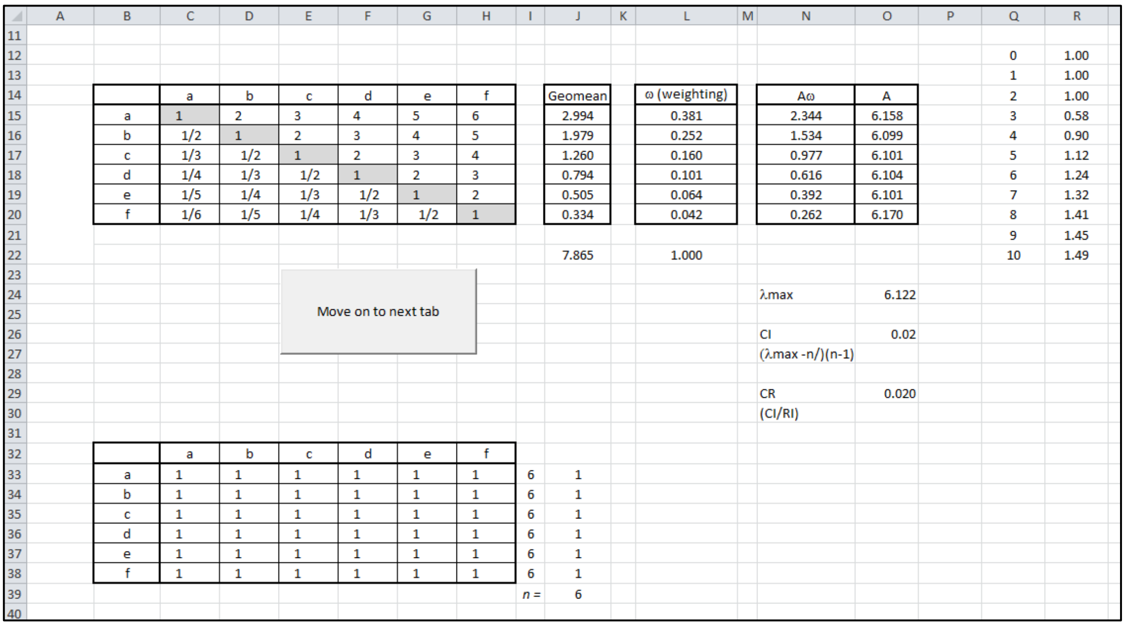
λmax	0.000
CI (λmax -n/)(n-1)	0.00
CR (CI/RI)	0.000

0	1.00
1	1.00
2	1.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Move on to next tab

	a	b	c	d	e	f		
a	1	0	0	0	0	0	1	0
b	0	1	0	0	0	0	1	0
c	0	0	1	0	0	0	1	0
d	0	0	0	1	0	0	1	0
e	0	0	0	0	1	0	1	0
f	0	0	0	0	0	1	1	0
							n =	0

Figure 4.24 – A matrix with no pairwise comparisons yet undertaken



	a	b	c	d	e	f	Geomean	ω (weighting)	Aω	A
a	1	2	3	4	5	6	2.994	0.381	2.344	6.158
b	1/2	1	2	3	4	5	1.979	0.252	1.534	6.099
c	1/3	1/2	1	2	3	4	1.260	0.160	0.977	6.101
d	1/4	1/3	1/2	1	2	3	0.794	0.101	0.616	6.104
e	1/5	1/4	1/3	1/2	1	2	0.505	0.064	0.392	6.101
f	1/6	1/5	1/4	1/3	1/2	1	0.334	0.042	0.262	6.170
							7.865	1.000		

0	1.00
1	1.00
2	1.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

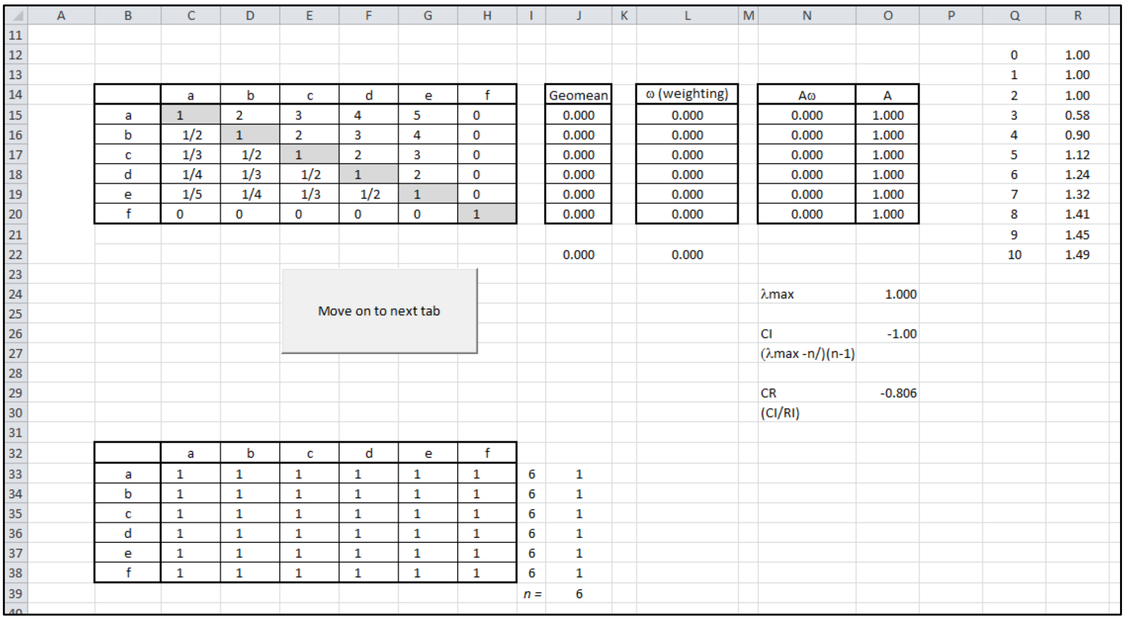
Move on to next tab

λmax 6.122

CI (λmax -n/)(n-1) 0.02

CR (CI/RI) 0.020

	a	b	c	d	e	f		
a	1	1	1	1	1	1	6	1
b	1	1	1	1	1	1	6	1
c	1	1	1	1	1	1	6	1
d	1	1	1	1	1	1	6	1
e	1	1	1	1	1	1	6	1
f	1	1	1	1	1	1	6	1
							n =	6



	a	b	c	d	e	f	Geomean	ω (weighting)	Aω	A
a	1	2	3	4	5	0	0.000	0.000	0.000	1.000
b	1/2	1	2	3	4	0	0.000	0.000	0.000	1.000
c	1/3	1/2	1	2	3	0	0.000	0.000	0.000	1.000
d	1/4	1/3	1/2	1	2	0	0.000	0.000	0.000	1.000
e	1/5	1/4	1/3	1/2	1	0	0.000	0.000	0.000	1.000
f	0	0	0	0	0	1	0.000	0.000	0.000	1.000
							0.000	0.000		

0	1.00
1	1.00
2	1.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Move on to next tab

λmax 1.000

CI (λmax -n/)(n-1) -1.00

CR (CI/RI) -0.806

	a	b	c	d	e	f		
a	1	1	1	1	1	1	6	1
b	1	1	1	1	1	1	6	1
c	1	1	1	1	1	1	6	1
d	1	1	1	1	1	1	6	1
e	1	1	1	1	1	1	6	1
f	1	1	1	1	1	1	6	1
							n =	6

Figure 4.25 – Fully functioning primary matrix compared with a primary matrix containing 0s

	a	b	c	d	e	f	Geomean	ω (weighting)	Aω	A
a	1	2	3	4	5	6	2.994	0.477	2.018	4.226
b	1/2	1	2	3	4	5	1.979	0.315	1.256	3.982
c	1/3	1/2	1	2	3	0	0.000	0.000	0.000	1.000
d	1/4	1/3	1/2	1	2	3	0.794	0.127	0.512	4.047
e	1/5	1/4	1/3	1/2	1	2	0.505	0.081	0.318	3.949
f	1/6	1/5	0	1/3	1/2	1	0.000	0.000	0.000	1.000
							6.272	1.000		

0	1.00
1	1.00
2	1.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Move on to next tab

λmax	2.541
CI (λmax -n/)(n-1)	-0.69
CR (CI/RI)	-0.558

	a	b	c	d	e	f		
a	1	1	1	1	1	1	6	1
b	1	1	1	1	1	1	6	1
c	1	1	1	1	1	1	6	1
d	1	1	1	1	1	1	6	1
e	1	1	1	1	1	1	6	1
f	1	1	1	1	1	1	6	1
							n =	6

Figure 4.26 – A primary matrix containing a 0 for the comparison of (c , f), causing a wrong value for λ_{max} and negative values for CI and CR

It is to combat these problems that the program has been developed to use a row/column of 1s to signify a switched off criteria. Equally, if a matrix was to be populated solely with 1s, it would create an equal weighting for all the criteria or alternatives, in relation to their parent criterion. As a result, this would not impact on the final result and adds support to their use in terms of logic.

For the same reason, 1s are used in the representation of the vector A, when a criterion is switched off. For the calculation of the estimation of λ_{max}, the elements of this vector are multiplied and the n^{th} route is taken. If any of the elements in the multiplication are presented as a 0, then the result is 0. If this was the case, the consistency checks would be incorrect. Therefore, a 1 is entered as an element of A, so that it does not affect the calculation of the estimation of the eigenvalue, λ_{max}.

4.11 Summary

The decision on the final structure of the hierarchy and composition of the matrices was an iterative process, and also highly time dependant. The changing nature of the requirements on the LA through legislation amendments meant that at various points, new decisions on the areas of importance had to be made. These include budget changes, legislative amendments, social acceptance and numerous other external factors that changed the route taken by the case study LA through time. This translated into problems when creating the decision support tool. The developer may think that it has been perfected for a particular study but in reality, further changes are almost certainly needed in the future.

As priorities and external factors change over time, so the process must evolve to reflect them. This is shown by the constant re-evaluation of the assumptions and associated changes in the decision tree. The initial limitation that food waste could not be addressed was reviewed and a simple analysis has been able to be included. The frequency was assumed to be able to be modelled and eventually was included. Through testing, the focus of the case study LA was narrowed and clearly defined on recycling in the main, followed closely by residual and food waste.

By reviewing the direction of the decision making route at regular intervals, these assumptions were revisited and revealed the shift in focus that occurred many times over. The assumptions made at each step reflect this course of actions. Without documenting the reasons for these changes in the decision tree, they would have no context. In this way, the case study LA can prove the reasoning behind why they make the decisions they do and show how it affects other areas. An example of this is the movement of the *'Public Perception'* module. It originally started as a criterion under *'Running Costs'*. After deliberation, it was deemed to have a more widespread impact than solely on the cost of a scheme, as outlined in section 4.9.1 , and moved up to the ***Drivers and Barriers*** layer.

To try to account for this, the tool was made to be adjustable and the user can decide to opt in/out of using certain criteria. This provides flexibility to the user depending on the current circumstances when a new decision is to be made. This is particularly highlighted in the inclusion-exclusion-inclusion of the quality of recyclate collected, in the decision making process. For the support tool to be truly user friendly, and correctly model 'real world' situations, the options must be available for the user to include whichever criteria and solution alternatives that they desire.

This follows the idea that decision making in this area is time dependant and the DST cannot be used once every four or five years. If run on a yearly basis for example, minor adjustments to a scheme (outside of contractual obligations) can be made, and subsequent reasoning can be justified. If a methodology is used to rationalise the implementation of an alternative, the use of the same methodology a year later brings consistency to the decision making process. It can be argued that the same criteria and options must be used to allow for comparable results. Equally, criteria and alternatives can be changed to reflect legislative changes in the ‘real world’.

The One Bag collection method, whilst not legislatively viable, was included in order to allow for rank preservation. However, if the user does not want to consider this as an alternative and cares not for rank preservation, it can be left out, as described in this chapter.

The final version of the hierarchy that was created, accurately covers the areas for consideration for a LA when considering a MSW collection scheme, by November 2014. It takes into account the time sensitive issues they face, whilst allowing flexibility to enable its use in a continuous evaluation procedure. Moreover, there is the capability to compare qualitative and quantitative data alongside each other, to allow the user’s expertise to form part of the decision making process.

5. Results & Discussion

5.1 Introduction

Preliminary results were gathered in tandem with the development phase of the decision tool and methodology outlined in Chapter 4. This iterative process helped to form the various decision trees seen in the previous chapter. The knowledge gained through testing, allowed the decision making process to be mapped and understood, depending on the factors deemed important by the decision maker(s). This also reflected the external pressures that changed over time, such as Government direction (WAG 2009) and legislative changes.

In Section 5.2 the characteristics of the decision making weightings are created. There are four types of characteristic that are based on how the weightings of the criteria are spread. These characteristics will later aid the explanation of the impact that criteria have on the decision making process.

In Section 5.3 the classification of LAs, dependent on their features is undertaken. Subsequently, analysis of the gathered results from questionnaires, concerning their views on the drivers and barriers they face is completed.

The LAs are separated into small, medium and large by population and whether they are predominantly rural, urban or compact urban authorities. The effects this has on their decision making process, provides evidence of the importance of each of the criteria for the LAs in Wales. How differing geosocial challenges impact upon the choices the authorities make, gives the first point of analysis.

In Section 5.4 the interaction of criteria from the drivers and barriers in relation to each other is examined to create scenarios. In these scenarios, one or more of the criteria are deemed more important than the others. The classification and characteristics of authorities are applied to the criteria to show how they affect the choice of solution alternative. Furthermore, the weighting of certain criteria on their sub-criteria shows the impact of their global importance. Their interaction and how the methodology impacts on the choice of solution alternatives, is the second point of analysis of the decision making process. In analysing how the characteristics and likely scenarios affect the different types of authority, an understanding of how the elements of importance affect the decision making process in waste collection is formed.

The scenarios are then compared to the decision making process of the Case Study Authority in Section 5.5 By comparing the decision they make to that of the results of the scenarios, it can be seen whether this particular authority reacts similarly to others of the same size and type, or not. The 'results' of the recyclate collection scenarios can then be paralleled to the decision made by the Case Study authority, giving a profile of the main areas of concern. In addition, the basic comparison of the food collection alternatives and its criteria are checked against the Case Study Authority's decision. The consequences of the results borne from this comparison, to that of the recyclate collection, will give an approximation to the accuracy of the decision made. The results from these two comparisons should be complementary to give a truly consistent choice with regards to waste collection. Finally in Section 5.6 the possibility of reclassification of the boundaries of the LAs of Wales is studied and the possible effects this may have on waste collection in Wales.

5.1.1 Decision Making Weightings

There are two areas of concern. Firstly, the actual decision making process itself and secondly, how the criteria interact with each other. Once these are understood separately, they can be interlinked to understand how the decision making process guides the interaction of drivers, barriers and any other criteria that face a LA, in a waste management context.

Criteria selection is very important. The drivers and barriers facing any LA informs their decision making process. Usually, short term reactive measures are taken by these authorities. To implement a successful collection scheme, proactive long term planning is required. Setting the correct criteria can positively affect an authority in the long term, leading to consistent decisions being made over an extended period of time. It is then only the solution alternatives, the methods of collection, that need to change as circumstances dictate.

As set out in Section 2.4.1, the description of the Analytic Hierarchy Process (AHP), the decision making weightings are the relative importance of each criterion in a set of pairwise comparisons, and their sum must equal 1.000. The set of pairwise comparisons in the ***Drivers & Barriers*** layer, which are carried out on a subjective basis by the decision maker(s) lead the decision making process. Figure 5.1 shows the decision tree and highlighted are the criteria that form the drivers and barriers.

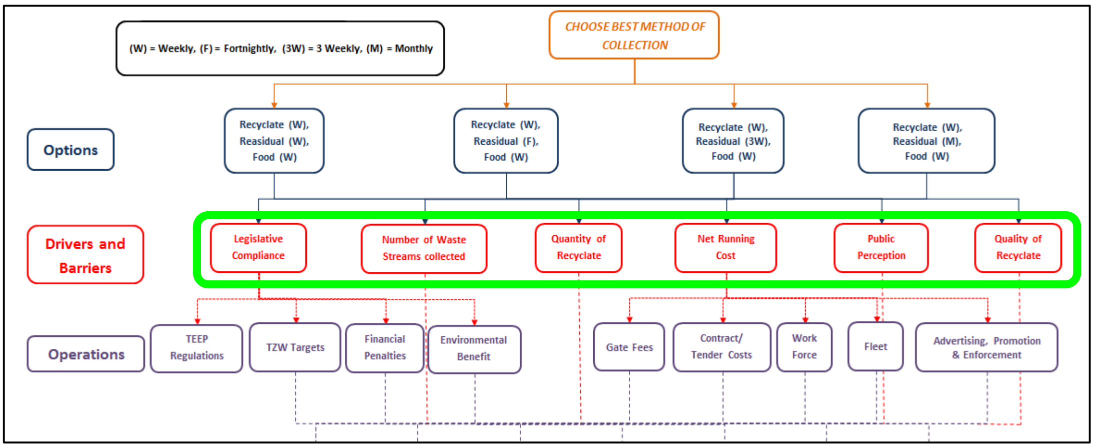


Figure 5.1 - The Decision Tree with the Drivers and Barriers encircled in green

The sub-criteria, in the ***Operations*** layer, under *Legislative Compliance* are pairwise compared subjectively, to show which is most important to the decision maker(s). The sub-criteria for *Net Running Costs* are pairwise compared using quantitative data, where numerical values are substituted by weightings. For clarification, depicted in

Table **5.1** are the relative sub-criteria for each parent criterion. These 2 sets of weightings for the sub-criteria, are multiplied by the weighting obtained in the pairwise comparison of the ***Drivers & Barriers*** for Net Running Costs and Legislative Compliance. In Figure 5.2, the global weighting results are circled in red, for an example set of weightings.

Next, the set of solution alternatives are pairwise compared to each other, with respect to the remaining four criteria in the ***'Drivers & Barriers'*** layer, not including Net Running Cost and Legislative Compliance. The solution alternatives are also pairwise compared with respect to the nine sub-criteria of

Table **5.1**, providing a total of thirteen sets of weightings. These comparisons are multiplied by the weightings shown, circled in red, in the cells *B12* to *N13* in box in Figure 5.3. They give the global weighting of the solution alternatives, with respect to each parent criterion in achieving the goal, finding the best method of waste collection.

These thirteen sets of comparisons are the values that populate the main body of the table, highlighted by the red boxes.

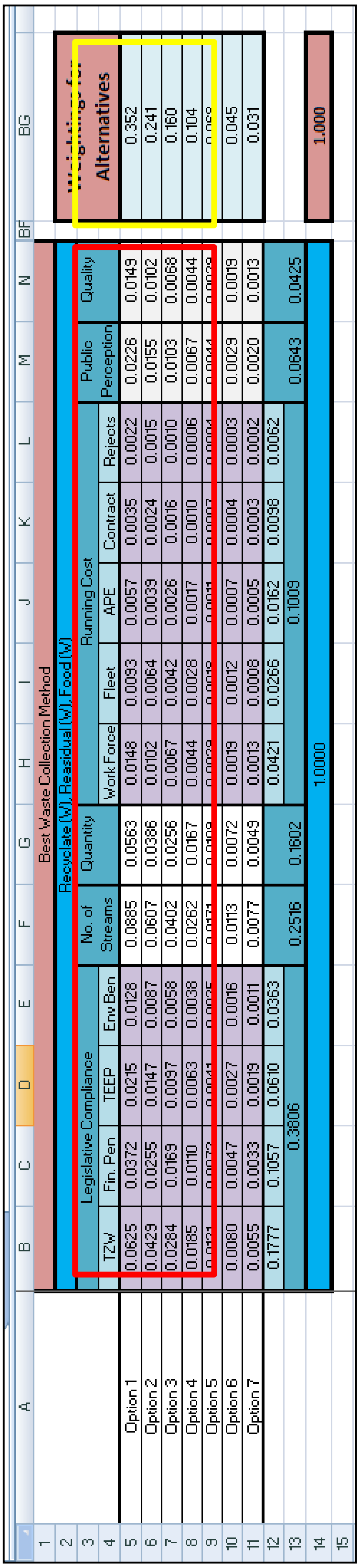
Table 5.1 - Parent Criteria and their sub-criteria

Parent Criterion	Sub-criteria
Legislative Compliance	Regulation 13 of the Waste Regulations – TEEP Regulations
	Toward Zero Waste (TZW) Targets
	Financial Penalties
	Environmental Benefit
Net Running Costs	Gate Fees
	Contract/Tender Costs
	Work Force
	Fleet
	Advertising, Promotion and Enforcement

B	C	D	E	F	G	H	I	J	K	L	
Best Waste Collection Method											
Recyclate, Reasidual, Food											
Legislative Compliance				No. of Streams	Quantity	Running Cost					Pu
TZW	Fin. Pen	TEEP	Env Ben			Work Force	Fleet	APE	Contract	Rejects	Perc
0.0625	0.0372	0.0215	0.0128	0.0885	0.0563	0.0148	0.0093	0.0057	0.0035	0.0022	0.0
0.0429	0.0255	0.0147	0.0087	0.0607	0.0386	0.0102	0.0064	0.0039	0.0024	0.0015	0.0
0.0284	0.0169	0.0097	0.0058	0.0402	0.0256	0.0067	0.0042	0.0026	0.0016	0.0010	0.0
0.0185	0.0110	0.0063	0.0038	0.0262	0.0167	0.0044	0.0028	0.0017	0.0010	0.0006	0.0
0.0121	0.0072	0.0041	0.0025	0.0171	0.0109	0.0029	0.0018	0.0011	0.0007	0.0004	0.0
0.0080	0.0047	0.0027	0.0016	0.0113	0.0072	0.0019	0.0012	0.0007	0.0004	0.0003	0.0
0.0055	0.0033	0.0019	0.0011	0.0077	0.0049	0.0013	0.0008	0.0005	0.0003	0.0002	0.0
0.1777	0.1057	0.0610	0.0363			0.0421	0.0266	0.0162	0.0098	0.0062	
0.3806				0.2516	0.1602	0.1009					0.0
1.0000											

Figure 5.2 - Sub-criteria weightings highlighted in red

When the rows are summed, this provides the overall weighting for each solution alternative. The alternative that has the highest value is the *suggested* best option to achieve the goal with this set of criteria, with these decisions. These values are circled in yellow, in Figure 5.3. If the residual collection is not previously decided, this is carried out a further three times if residual waste is collected, fortnightly, three weekly or monthly, due to the financial implications of this specific variation. An average of the four sets of AHP analyses can be taken or, if the collection of residual waste has been decided and agreed, the process need only be carried out once.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	BF	BG
1		Best Waste Collection Method														
2		Recyclate (W), Reasidual (W), Food (W)														Weightings for Alternatives
3		Legislative Compliance				No. of Streams	Quantity	Running Cost					Public Perception	Quality		
4		TZW	Fin. Pen	TEEP	Env Ben			Work Force	Fleet	APE	Contract	Rejects				
5	Option 1	0.0625	0.0372	0.0215	0.0128	0.0885	0.0563	0.0148	0.0093	0.0057	0.0035	0.0022	0.0226	0.0149		0.352
6	Option 2	0.0429	0.0255	0.0147	0.0087	0.0607	0.0386	0.0102	0.0064	0.0039	0.0024	0.0015	0.0155	0.0102		0.241
7	Option 3	0.0284	0.0169	0.0097	0.0058	0.0402	0.0256	0.0067	0.0042	0.0026	0.0016	0.0010	0.0103	0.0068		0.160
8	Option 4	0.0185	0.0110	0.0063	0.0038	0.0262	0.0167	0.0044	0.0028	0.0017	0.0010	0.0006	0.0067	0.0044		0.104
9	Option 5	0.0121	0.0072	0.0041	0.0025	0.0171	0.0109	0.0029	0.0018	0.0011	0.0007	0.0004	0.0044	0.0029		0.068
10	Option 6	0.0080	0.0047	0.0027	0.0016	0.0113	0.0072	0.0019	0.0012	0.0007	0.0004	0.0003	0.0029	0.0019		0.045
11	Option 7	0.0055	0.0033	0.0019	0.0011	0.0077	0.0049	0.0013	0.0008	0.0005	0.0003	0.0002	0.0020	0.0013		0.031
12		0.1777	0.1057	0.0610	0.0363			0.0421	0.0266	0.0162	0.0098	0.0062				
13		0.3806				0.2516	0.1602	0.1009					0.0643	0.0425		
14		1.0000														1.000
15																

Figure 5.3 - Global weightings that contribute to the weightings of the Solution Alternatives

5.1.2 What do the Criteria Represent

Whilst the criteria are generally self-explanatory, clarification on their exact meaning in the context of the study must be made. When making pairwise comparisons, their meaning must be understood depending whether the criterion is part of the comparison or if it is a parent criterion. Where the criteria of the ***Drivers & Barriers*** layer are being pairwise compared, the question is how important is criterion *a* to the decision maker(s) over criterion *b,* in the collection of recyclate. If the solution alternatives or sub-criteria are being compared, the question is how well does option *a* achieve the criterion from the ***Drivers & Barriers*** layer, over option *b*. The definitions below are the meanings of the criteria when pairwise compared to each other:

- *Legislative Compliance* is the judgement that all legislation must be appeased.
- *Number of Waste Streams* is how many types of recyclate are collected.
- *Quantity of Recyclate* is the absolute mass of recyclate collected.
- *Net Running Cost* is the overall cost of delivering a collection scheme, when all costs (unless otherwise stated) are taken in to consideration.
- *Public Perception* is the acceptance (or likelihood of acceptance) of the general public, of the collection scheme.
- *Quality of Recyclate* is the quality of recyclate collected.

When considered as parent criteria, the sub-criteria/solution alternatives are given a higher pairwise comparison in the following way:

- *Legislative Compliance* – which of the sub-criteria/solution alternatives meet the legislative targets.
- *Number of Waste Streams* – which of the solution alternatives collect the widest range of recyclate streams.
- *Quantity of Recyclate* – which of the solution alternatives collect the highest mass of recyclate in a given time frame.
- *Net Running Cost* – which of the sub-criteria have the highest cost.
    - The lower the solution alternative costs, when pairwise compared with regards to the sub-criteria, the higher the weighting attained.
- *Public Perception* – which of the solution alternatives is most likely to be accepted by householders.

- *Quality of Recyclate* – which of the solution alternatives achieves the highest quality recyclate.

5.1.3 What do the comparisons mean?

Dependent on the number of criteria in the set that are being compared, the value assigned has different meanings. If there are four criteria, any criterion weighting over the value of 0.400, will have a large influence. This means, for the decision maker(s), this criterion is of high importance. It should be satisfied by giving more attention than the other criteria, as it is believed to be the main driver in achieving the goal or appeasing the parent criterion. For example, if *Legislative Compliance* has a weighting of over 0.400 in relation to the goal, then achieving legislative mandates is expected before all else. Addressing all legislation, regardless of cost, social acceptance and any other factors, must be completed first. Only then can the decision maker(s) address the next highest weighted criterion. In achieving the second 'favourite' criterion, the first must not be adversely affected, in this example *Legislative Compliance*.

If the second, third or more criteria are evaluated to be closely weighted, they may be considered in tandem with each other. Using the above example, if *Net Running Cost* and *Quantity* are a close second and third; by keeping running costs as low as possible, a drive for an increase in the quantity of recyclate collected may compliment this, whilst not adversely affecting legislative targets/regulations.

The same is true if there are five criteria, with any weighting of 0.300 or more having the largest influence. If there are six criteria, a weighting over 0.250 will have the largest influence. As the number of criteria increase, the necessary value of their weighting decreases, for an increase in the influence it has over the route taken and the selection of a solution alternative.

The decision making weightings have an effect on the representation of data in different ways, depending on whether they are calculated based upon quantitative or qualitative data.

5.1.3.1 Quantitative

If they are quantitative data based criteria, such as *Quantity of Recyclate* collected and the sub-criteria of *Net Running Costs*, the weightings are based upon absolute numerical values. Therefore there are limits set, representing whether one criterion is deemed to be unequivocally superior, slightly better or the same as another. If the numeric values of two criteria are the same, or within a specified tolerable amount, then their pairwise comparison will be recorded as a 1. Where there are differences in numeric values between two criteria, then it is at the discretion of the decision makers(s) to set the interval gaps, which define the pairwise comparison allocation for that set.

The programme was tested with intervals of £0 - £10,000 between two criteria represented by 1 in the pairwise comparison, £10,001 - £20,000 represented by 2 in favour of the cheapest criterion, etc. It was found that these intervals were too narrow and one criterion was given all 9s, which did not accurately represent the importance of each criterion. To give an accurate representation, the calculation of these intervals is sum of total monetary cost and then divided by seventeen, the number of potential weightings between 9 and 1/9.

Using quantitative data to carry out the pairwise comparisons will automatically give consistent results, so long as the intervals are truly representative of the data. The methodology will follow that if criterion *a* costs less than criterion *b* (giving *a* a higher weighting than *b*), and criterion *b* costs less than criterion *c* (giving *b* a higher weighting than *c*), then criterion *a* will cost less than criterion *c* (giving *a* a much higher weighting than c). It follows that the weightings will be:

$$\textbf{If:}\quad a>b \qquad \textbf{then:}\quad b>c \qquad \textbf{and:}\quad a>>c \qquad (5.55)$$

The weightings will always be consistent, reflected by a low Consistency Ratio (CR). This gives extra confidence in using the method because it is easily understandable for a decision maker.

5.1.3.2 Qualitative

Where qualitative data is used, the opinions of the decision maker(s) are required to decide the weightings of the criteria. Where the most importance is placed requires careful consideration so that the relative importance of the criteria included can be truly assessed. It differs from quantitative based weightings because opinion based weightings do not always follow Equation 5.1. For example, if person X was asked which they prefer out of apples, bananas and pears. Person X may prefer apples over bananas, bananas over pears but pears over apples. This does not follow the convention for calculating weightings using quantitative data. The qualitative data reflects the decision maker's opinion which is important in the waste management sector, owing to the input necessary of experienced stakeholders. Sometimes human decision making cannot be completely consistent!

5.1.4 Which areas are likely to be of most importance?

The outcome of the comparison between the criteria of the ***Drivers & Barriers*** layer is the most important as the priorities dictate the direction of the hierarchy (Saaty 1980). This is a subjective choice. It outlines to the user, where the overriding emphasis or emphases of their decisions lie. As explained in Section 4.5, the iterative testing phase led to the decision to include only these six criteria as the drivers and barriers and these seven solution alternatives. The *Net Running Cost* will likely be a very important area of concern due to continual budgetary pressures on LAs, through diminishing available funds, whilst maintaining levels and standards of recyclate collection. *Legislative Compliance* may be high in importance due to the potential fines of not achieving targets. This could then lead on to further action against authorities, should legislation not be adhered to. *Public Perception* may figure highly, as without increased householder's knowledge and acceptance of a scheme, the recyclate collection can diminish (Emery et al. 2004).

The ordering of the *Net Running Cost* sub-criteria is important as the financial components can vary greatly, i.e. the *Work Force* usually costs more than *Advertising, Promotion and Enforcement* (*APE*). With increasing yearly financial restrictions imposed on LAs, invariably monetary implications will be of great interest. These comparisons are predetermined due to the use of quantitative data.

Under *Legislative Compliance*, this will reveal which areas of legislation are most important to the authority and therefore what they want to achieve as a priority. If it is Regulation 13 of the amended Waste (England and Wales) Regulations (2012), then quality *should* be of importance. If it is the recycling targets outlined in the Waste (Wales) Measure (2010), then quantity *should* be important.

The alternatives must be truly representative of the possible choices that are available to the LA. If there are too many or there is too much information, the decision making process becomes cumbersome and confusing, leading to a poor decision (Hall et al. 2007) thanks to a 'watered down' result. With too many solution alternatives, it may diminish the strength of the favoured choice or cause the choice of a collection scheme that is actually less favourable overall. The solution alternatives must previously have been narrowed down to the main contenders, as per the decision making route map in Section 1.2. In the instance of the Case Study Authority, this has been carried out.

The *'Business as Usual'* solution alternative, or any slight variation thereof, will likely be considered as forefront in the view of most authorities. Using a current system represents the least financial expenditure and householders are already using the system. This does not necessarily mean that it is the best choice for a waste collection method. There may be improvements on the service that increase the quantity and/or quality of the recyclate collected. Legislation may have changed and therefore requires a change in collection. Whatever the reason, a full appraisal of the system and, more importantly, the decision making process, is required.

5.2 Characteristics through Weightings

Once the weightings have been calculated, they can be organised into characteristics, to better aid understanding. These express the type of decision made in relation to whether the criteria are considered fairly similar, or if stronger disparities in importance are expressed. Also characteristics can be used to see how these influence the decision made, with regards to the type of authority and their collection methods.

The examples that follow contain pairwise comparisons that are as close to 'perfect' as possible. In practice, this may not happen, however it serves the purpose of giving weightings that can be categorised into the characteristics. The criteria are referred to generically in the following cases as *a*, *b*, *c*, *d*, *e* and *f*. Where *a – f* represent the solution alternatives, the pairwise comparisons show how well one collection method achieves the criterion compared to another. Where *a – f* represent criteria, the pairwise comparison shows the importance of one criterion over another in the success of a collection scheme in the opinion of 'the authority'.

Hypothetically, the weightings are 'reverse engineered' i.e. the result is known and it is assumed that the order of importance is *a, b, c, d, e, f* from most to least important, the characteristics can be built to study the impact of various types of weighting. These are titled:

- Linear Weighting characteristic suggests that the weightings from pairwise comparisons are in regular steps. This means the comparison *a:f* would have a weighting of 9 and *a:b* would have a weighting of 2. The other three pairwise comparisons would be linearly incremental between these two values. When the weightings are calculated, a reasonably linear line can be seen.

- Top Heavy Weighting characteristic suggests that one criterion has a much higher importance than the remaining five (in the example of six criteria under comparison). If one criterion is evidently more important, either the majority of its pairwise comparisons or all of them will be valued as 8s or 9s. The remaining criteria would be assessed in the usual fashion.

- Proximate Weighting characteristic suggests that the weightings are very close together. The full range of values may not be necessary (no 8s or 9s are assigned as weightings) and the criteria are considered to be similar in importance. It would be expected that the pairwise comparisons would contains values mostly in the region of 1-3.

- Split Weighting characteristic would signify that there is a clear division between one set of the criteria under comparison, to the other. It is similar to Top Heavy weighting, however there must be more than one criterion that is set apart, in terms of importance from the rest. It follows that if two criteria, *a* and *b* for example, are more important, comparisons *a:c* and *b:c* will have values of 7 upwards, *a:b* will be either equal, a value of 2 or a ½ and the remainder would be assessed in the usual fashion. There are many pairwise comparison permutations that may occur in this characteristic, but the split of the weightings is key.

A more in depth explanation of these characteristics and their significance to the decision making process follows.

5.2.1 Linear Weighting Characteristic

If *a* is the most important and *f* the least, in a hypothetical situation it can be assumed that it is likely the user would input a 9 for comparison *a*:*f*. If the difference between each criterion is linear, and assuming there are no equal importance criteria, then the comparisons would be translated into a matrix, giving Table 5.2. Although the pairwise comparisons are incremental and linear, the weightings are almost doubling from one to the next. This means that criterion *a*, as expected, is deemed to be the most important. Moreover, criteria *d*, *e* and *f* have a relatively small impact on the decision. When summed, these three have a similar impact as criterion *c*, highlighting this. The criteria *d, e* and *f* in this case are relatively small values, signifying they are deemed to be of little importance to the decision maker.

If the decision is as per Table 5.2, the CR is valued at 0.009, showing that the decisions are extremely consistent. While in theory this could be possible, it is unlikely, as human decision making is inherently inconsistent (Summerfield and Tsetsos 2014). In practise, the pairwise comparisons may not be so linear, however the weightings can still end up with a Linear Weighting characteristic. With a Linear Weighting characteristic, the weightings assigned to the criteria start high and have a slow decrease towards the least important criterion, shown in Figure 5.4. In terms of the decision making process, the criteria will each have an ever decreasing impact. When translated into the global weightings, they will have the similar effect to the solution alternatives i.e. *a* will contribute much more to the alternative's final weightings than *f*.

Table 5.2 - Linear weighting pairwise comparison matrix

	a	b	c	d	e	f
a	1	2	3	5	7	9
b	1/2	1	2	3	5	7
c	1/3	1/2	1	2	3	5
d	1/5	1/3	1/2	1	2	3
e	1/7	1/5	1/3	1/2	1	2
f	1/9	1/7	1/5	1/3	1/2	1

ω (weighting)
0.413
0.255
0.154
0.090
0.054
0.033

CR = 0.009

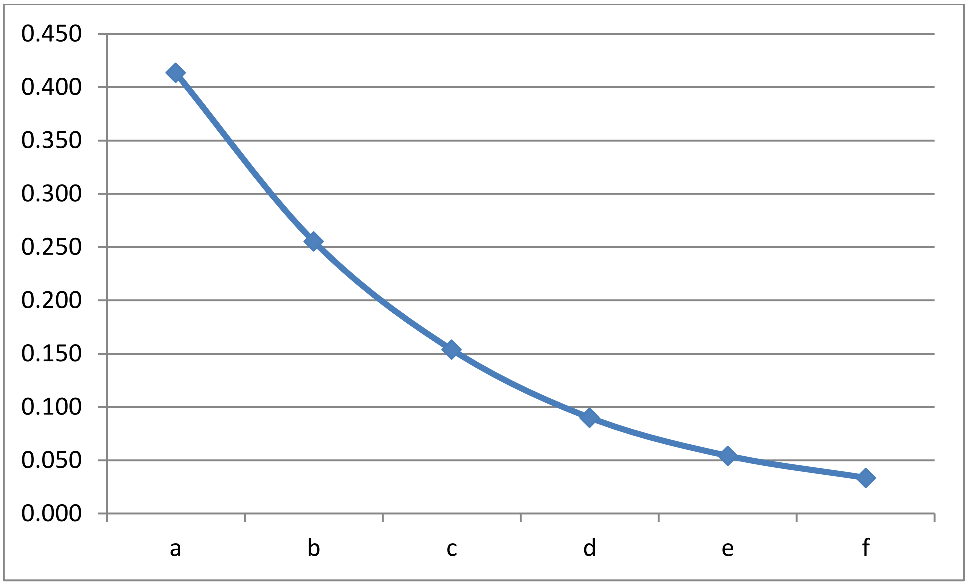


Figure 5.4 - Graphical representation of the Linear Weighting Characteristic

5.2.2 Top Heavy Weighting Characteristic

For a Top Heavy Weighting characteristic, criteria *a* is assumed to be of highest importance. This translates to the criterion *a* having a pairwise comparison of 9 with every other criterion, as shown in Table 5.3. The remainder are compared by the decision maker(s) to decide on the weighting of each criterion. The effect this has is that criterion *a* will have the largest influence upon the decision. The graphical representation of the hypothetical weightings is shown in Figure 5.5, where *a* has a weighting of 0.606. This translates to the sum of the remaining criteria at about 0.4. Therefore, criteria *b* through *f* will have little impact on the overall outcome individually. This translates to criterion *a* having a large impact on the global weightings for the selection of a solution alternative, with the remainder having little input.

In relation to the decision making process, the majority of the criteria will have a minimal input to the final weightings of the solution alternatives. If *a* to *f* indicate the solution alternatives in Figure 5.5, then the contribution will mainly be from *a*, and aid in strengthening the weighting of the alternative represented by *a*. The remainder will have an almost insignificant contribution to the weighting of the remaining alternatives. Table 5.3 has a CR of 0.063, showing it is still a consistent decision matrix.

Table 5.3 - Top Heavy pairwise comparison matrix

	a	b	c	d	e	f	ω (weighting)
a	1	9	9	9	9	9	0.606
b	1/9	1	2	3	4	5	0.150
c	1/9	1/2	1	2	3	4	0.102
d	1/9	1/3	1/2	1	2	3	0.067
e	1/9	1/4	1/3	1/2	1	2	0.045
f	1/9	1/5	1/4	1/3	1/2	1	0.030

CR = 0.063

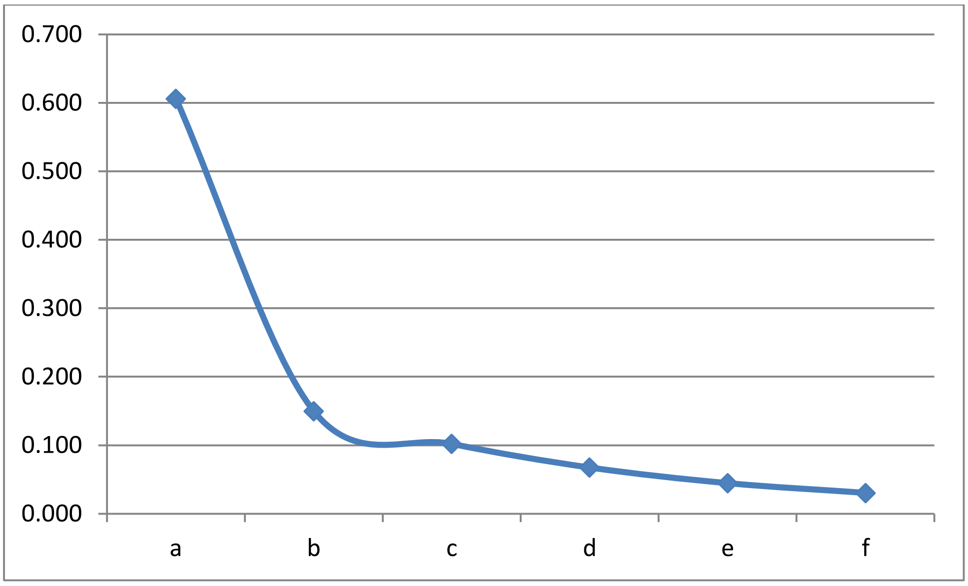


Figure 5.5 - Graphical representation of the Top Heavy Weighting Characteristic

5.2.3 Proximate Weighting Characteristic

Proximate weighting will give the criteria under scrutiny a similar impact scale on the overall decision to be made. None of the criteria, through pairwise comparison, extremely outweigh each other, meaning that they are of a very similar importance. In Table 5.4, the pairwise comparisons are within a very small range of numbers, and none exceed the value of 3 (and inversely 1/3), strengthening the argument that the criteria are similarly valued. Figure 5.6 shows the weightings of *a* to *f*, although decreasing slightly, are all similar.

It means that the solution alternatives will all have a fairly even contribution to their weightings, from this criterion. The effect this has on the decision making process is almost negligible because the weightings of the solution alternatives, when represented as *a* to *f*, are increased by similar values, thus negating a benefit to any one alternative. The weightings are all between 0.222 and 0.137. The CR value of Table 5.4 is 0.073. Even though there are a couple of discrepancies in terms of logic, where comparisons *b:c* and *c:f* are reciprocals, this is allowed if the limit for the CR is 0.1.

Table 5.4 - Proximate Weighting pairwise comparison matrix

	a	b	c	d	e	f
a	1	1	1	2	1	3
b	1	1	1/2	1	2	2
c	1	2	1	1	1	1/2
d	1/2	1	1	1	1	1
e	1	1/2	1	1	1	1
f	1/3	1/2	2	1	1	1

ω (weighting)
0.222
0.184
0.164
0.146
0.146
0.137

CR = 0.073

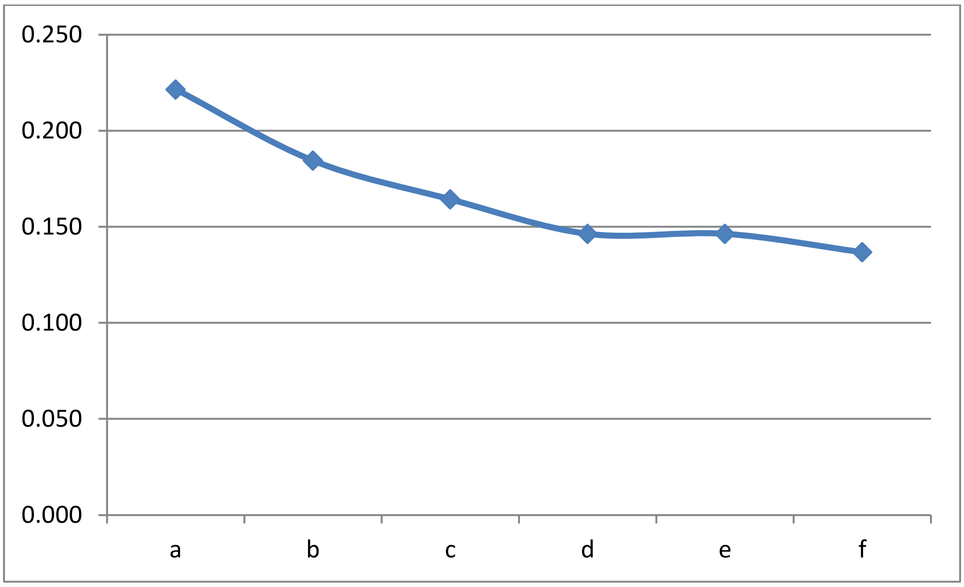


Figure 5.6 - Graphical representation of the Proximate Weighting Characteristic

5.2.4 Split Weighting Characteristic

Split Weighting characteristic signifies that two or three of the criteria are much more important than the remaining criteria. In Table 5.5, three criteria are deemed similarly more important than the other three and shows how these weightings may occur. It is clear from comparisons *a:b*, *a:c* and *b:c* that these three are considered similar in importance to each other from the assigned weightings of 1, 2 and 1 respectively. In the same way, criteria *d*, *e* and *f* are considered similar in importance through the assigning of 2, 3 and 2 to comparisons *d:e*, *d:f* and *e:f*. The comparisons between *a*, *b*, *c* and *d*, *e*, *f* reveal the split in importance. With comparisons of no less than 5 and going up to 9, the weighting of each criterion shows the split between the two sets of three criteria and is further illustrated by Figure 5.7.

This means that *a*, *b* and *c* have a large impact on the decision of solution alternative, however the others bear little to no impact. When one criterion has a weighting of 0.315 compared to 0.028, there is a difference of more than 10 times. Invariably, the impact is much greater for criterion *a* than that of criterion *f* on the final decision made. Again, consistency in the decision is shown by a CR of 0.025, much below the 0.1 threshold.

Table 5.5 - Split Weighting pairwise comparison matrix

	a	b	c	D	e	f
a	1	1	2	6	6	8
b	1	1	1	5	8	9
c	1/2	1	1	6	7	9
d	1/6	1/5	1/6	1	2	3
e	1/6	1/8	1/7	1/2	1	2
f	1/8	1/9	1/9	1/3	1/2	1

ω (weighting)
0.315
0.292
0.262
0.062
0.041
0.028

CR = 0.025

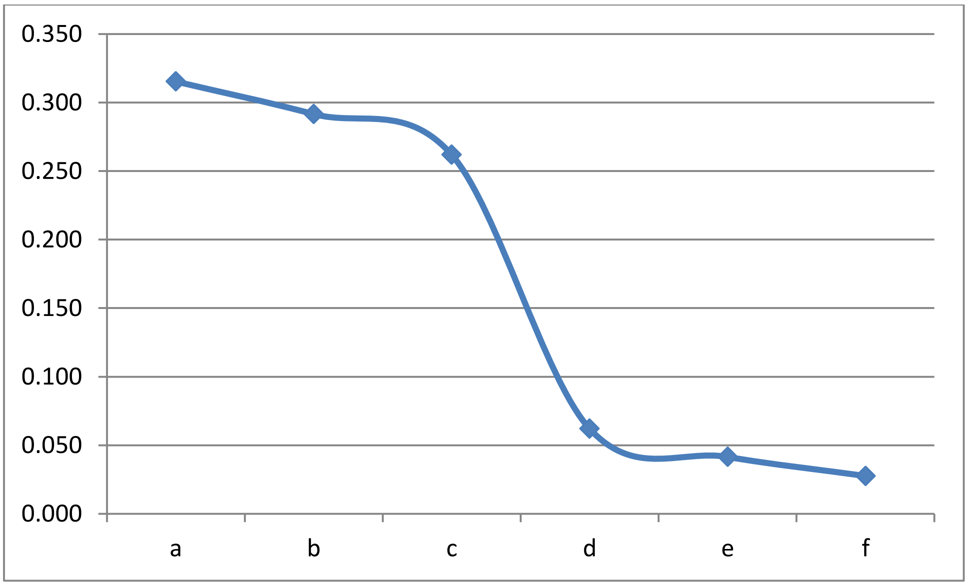


Figure 5.7 - Graphical representation of the Split Weighting Characteristic

5.3 Local Authority Classification depending on Size and Type

5.3.1 Introduction

The unitary authorities in Wales can be categorised in two ways, either by size of general public population or by type. In size they can be classed as small, medium or large with populations of 120k or less, between 120k and 140k, and 140k or larger respectively. The type of authority can be predominantly rural, predominantly urban or a compact urban authority (an authority that is predominantly a major city).

Using these methods of grouping the authorities are ranked in

Table 5.6. There are 8 small, 7 medium and 7 large authorities and there are 7 urban, 10 rural and 5 compact urban authorities. In terms of interaction of the two types of classification it can be seen that the majority that are classified as small are also rural, the medium classification are a mixture of urban and rural and the large classification are mostly also compact urban authorities.

At a glance, an authority that is predominantly rural with a small population faces the challenge of higher costs of collection per tonne of recyclate, on account of a relatively low amount of recyclate for the large distance and difficult terrain traversed. This drives up the cost per tonne of recyclate collected, as the vehicles must cover a higher mileage to reach different towns and villages that are spread throughout the authority. On the other extreme, a compact urban authority with large population is more densely populated, such as Cardiff for example. The waste collection scheme for such an authority can gather more recyclate whilst covering less mileage, potentially lowering the cost of collection per tonne of recyclate. However, for such an authority, the type of housing tends to be more diverse and can consequently become a problem. There is likely to be more flats to contend with and so, would a kerbside sort collection, with many receptacles, be plausible for such residents? Also, if there is a communal bin area where waste and recyclate is collected from, there is anonymity in the deposition of waste. This causes difficulties when trying to direct feedback to householders, as the operatives cannot leave messages to particular individuals that have misused the service.

A medium authority generally has a mixture of rural and urban areas, with pockets of denser populations and also larger rural areas to cover. Their basic issues are centred on how to provide a service that best caters to a varied landscape such as this. The management of rural areas will require different techniques to those employed in urban areas. How do the criteria impact on their decision?

Table 5.6 - Classification of all Welsh Authorities by Size and Type (StatsWales, 2014)

Local Authority	Population	Type of Authority
Isle of Anglesey	69,751 (Small)	Rural
Blaenau Gwent	69,814 (Small)	Urban
Bridgend	139,178 (Medium)	Urban
Caerphilly	178,806 (Large)	Urban
Cardiff	346,090 (Large)	Compact Urban
Carmarthenshire	183,777 (Large)	Rural
Ceredigion	75,922 (Small)	Rural
Conwy	115,228 (Small)	Rural
Denbighshire	93,734 (Small)	Rural
Flintshire	152,506 (Large)	Compact Urban
Gwynedd	121,874 (Medium)	Rural
Merthyr Tydfil	58,802 (Small)	Urban
Monmouthshire	91,323 (Small)	Rural
Neath Port Talbot	139,812 (Medium)	Urban
Newport	145,736 (Large)	Compact Urban
Pembrokeshire	122,439 (Medium)	Rural
Powys	132,976 (Medium)	Rural
Rhondda Cynon Taff	234,410 (Large)	Urban
Swansea	239,023 (Large)	Compact Urban
Torfaen	91,075 (Small)	Urban
The Vale Of Glamorgan	126,336 (Medium)	Rural

Wrexham	134,844 (Medium)	Compact Urban

At a conference in August 2014, all Welsh authorities were present and represented by staff in various positions within their authorities. They were handed a questionnaire, to place the criteria in order of those which are most important to them down to those they believe are least important. They had to identify the authority they represent by the above classifications. The criteria are those found in the ***Drivers and Barriers*** layer and are taken as those that are considered by all authorities. The findings from these questionnaires led part of the changes within the tool and the decision tree, as outlined in Chapter 4. Dependent on the user, and therefore the classification of the authority they represent that would use the methodology, directly impacts upon the results that can be extracted. These classifications are necessary to understand the interaction of drivers and barriers that influence their decisions. This later gives the opportunity to link them up with the characteristics defined in Section 5.2 to create scenarios.

The University Ethical Policy was adhered to when the research was first put forward, leading to the Studentship Agreement shown in Appendix 1. The University's policy is included in Appendix 2. As per the section 'Issues to consider when providing information to Potential Participants', these bullet points were explained to the participants before they gave their answers.

Of the returned questionnaires, the issue must be addressed as to whether they are enough (in number) and are they representative of decision makers that would use the methodology. With regards to enough, there are less replies from the large authorities and compact urban authorities, this was unavoidable. Whilst it would have been preferable to obtain more, participation in such activities was very difficult. However, a simple statistical analysis reveals that for the population of 48 across all authorities at the 95% confidence level, a sample size of at least 17 is required, allowing a margin of error of 15%. This means the sample size of 19 responses obtained is satisfactory.

With regards to whether the sample was representative, although participation was anonymised, there were many who were unwilling to put their preferences down and be named. However, the author ensured that those who did fill in the questionnaires were decision makers in their area of waste management, for their authority. Therefore, it can be assumed that the answers that were given can be classed as representative (McDonald 2012).

5.3.2 Classification by type

If the authorities are classified by type, the emphasis is on whether they are a rural, an urban or a compact urban authority. The geographical issues this raises provides a second method of comparison. It would be expected that rural authorities, which have to cover further ground or deal with geographical hindrance (e.g. hills) to collect waste, will have pressures on cost per tonne of recyclate or waste collected. An urban authority will likely focus their attention on the public perception as they have shorter distances to travel to collect waste. A compact urban authority has differing demographics and many varied household types, such as flats, terraced housing, detached housing etc., to contend with. The focus here may be more on the alternatives that can cope with these challenges.

Stakeholders in the collection of waste in LAs were asked to prioritise the criteria of the ***Drivers and Barriers*** using a simple additive method. This meant that the criteria in the Drivers and Barriers were rated from 1 to 6, with respect to which the stakeholders believe are the most important in relation to their authority. The most important was valued at 6, through to 1 being the least important. The results of the authorities using this method are shown below.

The characteristics outlined in Section 5.2 are used to begin to show the opinions given by the authority. The values that were attained are converted in to percentages to give an importance rating. The percentage is calculated by dividing the Sum Weighted Method value assigned, by the maximum possible. The maximum possible is 6 multiplied by the number of people that returned the questionnaire for that classification. The higher the percentage, the more important the authority classification, as a whole, considers that criterion to be, in achieving the best method of recyclate collection.

5.3.2.1 Rural Authorities

It can be seen in Table 5.7 for the rural authorities, there is a Split Weighting characteristic where the *Net Running Costs* and *Quality of Recyclate* are considered more important than the remaining four. Scores of 20 and 19 out of a possible 24 place them at 83% and 79% of importance rating. In theory, this would lead to a determination to drive down the cost of collection as much as possible, whilst increasing the quality of recyclate collected. If these were both to be the ideals of a rural authority, there is a contradiction in direction. To gain better quality, more time is needed to inspect the recyclate or newer technology is needed to better sort it. This leads to either a higher cost through more operatives needed or further investment in technology thereby driving up spending.

If the authority were to focus on driving down costs, then the quality would likely suffer. Less frequent collection of residual waste would bring down costs for the LA, but may also reduce the quality of recyclate. Householders could have a reduced confidence in the service and use recyclate receptacles to dispose of residual waste. Equally, if less operatives were used on a collection route, the inspection of recyclate would have to be quicker, and therefore of a lower standard, if they were to complete the collection round in the same amount of time.

Of the other four criteria, *Legislative Compliance* is ranked as fourth, with a score of 50%. This suggests that the legislation in place, while of just lower importance than the *Quantity of Recyclate* collected with 58% and just above the *Number of Waste Streams* collected with 46%, is not stringent enough or being enforced. In theory, *Legislative Compliance* would be of paramount importance in this instance, as non-compliance would lead to fines. This would increase the net running cost of the service, which they consider to be most important of all the criteria, implying that compliance is not strictly enforced and for this reason falls lower in the order. When transferred to AHP Weightings, this Split Weighting Characteristic can be seen more clearly in Figure 5.8, a result of the matrix in Table 5.8. Net Running Cost and Quality of Recyclate account for 0.728 of the overall weighting.

Table 5.7 – Importance of Drivers and Barriers for a Rural Authority

						Total	Importance Rating
Net Running Cost (a)	6	6	5	3		20	83%
Quality of Recyclate (b)	5	4	6	4		19	79%
Quantity of Recyclate (c)	5	1	3	5		14	58%
Legislative Compliance (d)	4	3	4	1		12	50%
No. of Waste Streams (e)	2	2	1	6		11	46%
Public Perception (f)	3	1	2	2		8	33%

Table 5.8 - Pairwise comparisons based on questionnaire findings

	a	b	c	d	e	f	Weighting
a	1	2	4	6	7	9	0.403
b	1/2	1	5	6	7	8	0.325
c	1/4	1/5	1	3	4	6	0.131
d	1/6	1/6	1/3	1	2	4	0.069
e	1/7	1/7	1/4	1/2	1	3	0.047
f	1/9	1/8	1/6	1/4	1/3	1	0.025

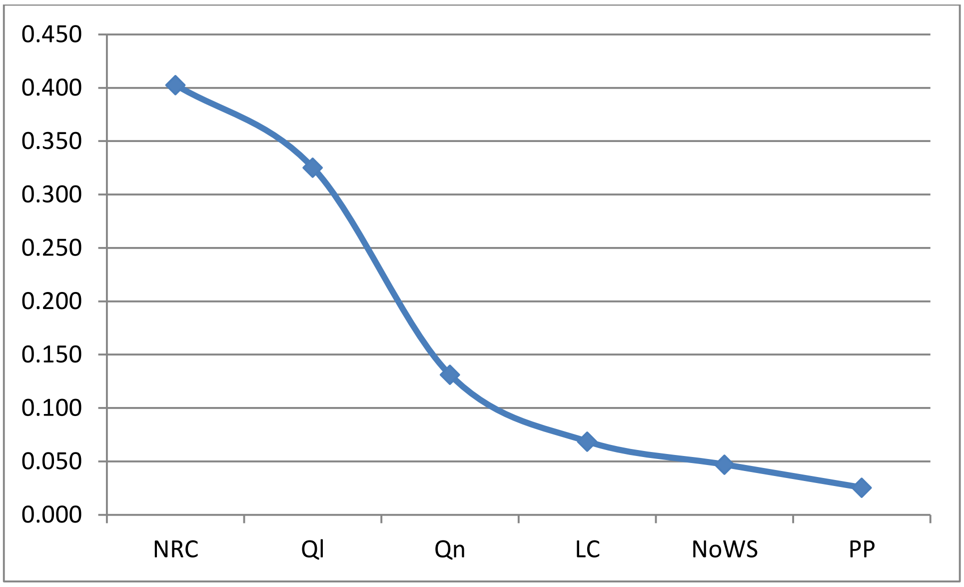


Figure 5.8 - Split Weighting Characteristic for AHP weightings in Rural Authorities

5.3.2.2 Compact Urban Authorities

For the compact urban authorities, there is a clear distinction between one criterion and the remainder as shown in Table 5.9, giving a Top Heavy Weighting characteristic. The first is *Legislative Compliance* on its own with a value of 38 out of a possible 42, giving an importance rating of 90%; followed by *Quality of Recyclate* (69%) and step changes from *Net Running Cost* (60%), *Quantity of Recyclate* (50%), *Public Perception* (43%) and the *Number of Waste Streams* collected (38%) at the bottom. This means that although there is one stand out criterion that is most influential on the choice made, the remainder are not insignificant.

With *Legislative Compliance* being the most important, changes in the Regulations would have the most disruption in the opinion of the compact urban authorities that returned the survey. In order to maintain compliance the authority must therefore be able to adapt to alterations in legislation and have a flexible service. This might lead to a favouring of commingled collections to more easily allow the flexibility of new materials to be collected or possibly a hybrid system of kerbside sort and commingled collection.

This is key to an authority that has many various types of dwelling to service. For a uniform collection across a compact urban authority, alterations to the service due to legislative changes, coupled with mixed housing, must by its definition be adaptable. The quality of the recyclate collected cannot drop however. As it is second most important for this classification, then the input is still significant and narrows the likely choice of solution alternative. With the *Net Running Cost* being of lower importance, it may also mean that the authority type is willing to invest in extra fleet or processing facilities to easily cope with any changes in legislation and therefore, to its service.

With *Quality* and *Quantity of Recyclate* collected and the *Net Running Cost* being closely grouped, the authority could consider these in tandem with each other. When considered in the same way that rural authorities consider *Quality of Recyclate* and *Net Running Cost* to be almost as important as each other, a compact urban authority can do so, with the inclusion of *Quantity of Recyclate*. This can aid in the running cost of a scheme. If the cost is considered in terms of cost per tonne of recyclate collected, then the higher the quantity, the cleaner the recyclate and more efficient the round is, the cheaper it will be. Quality is still second in the opinion of the compact urban authorities. Therefore, the quantity of recyclate that would be collected cannot be increased with complete disregard for its quality. On the other hand, if a rise in quality is sustained, then there is an argument that the cost per tonne collected can decrease. Less reprocessing that is required of recyclate can lead to a drop in costs and a higher quality receives a higher price at market.

With three criteria being of significant importance, if considered together, their impact on the decision can be influential on the choice of alternative. Again, with *Public Perception* and the *Number of Waste Streams* being so far below the previously mentioned criteria, their influence will be minor, maybe to the point of negligibility.

Table 5.10 and Figure 5.9 show the AHP weightings based on the questionnaire findings. *Legislative Compliance* has a weighting of 0.516, giving it a large influence over the other criteria.

Table 5.9 - Importance of Drivers and Barriers for a Compact Urban Authority

									Total	Importance Rating
Legislative Compliance (a)	3	5	6	6	6	6	6		38	90%
Quality of Recyclate (b)	4	6	4	4	2	4	5		29	69%
Net Running Cost (c)	6	2	2	5	1	5	4		25	60%
Quantity of Recyclate (d)	5	3	5	3	3	1	1		21	50%
Public Perception (e)	2	1	3	1	5	3	3		18	43%
No. of Waste Streams (f)	1	4	1	2	4	2	2		16	38%

Table 5.10 - Matrix for Pairwise Comparisons of Compact Urban Authorities

	a	b	c	d	e	f	Weighting
a	1	5	6	7	8	9	0.516
b	1/5	1	3	4	5	6	0.212
c	1/6	1/3	1	3	4	5	0.127
d	1/7	1/4	1/3	1	3	4	0.075
e	1/8	1/5	1/4	1/3	1	2	0.042
f	1/9	1/6	1/5	1/4	1/2	1	0.029

CR = 0.077

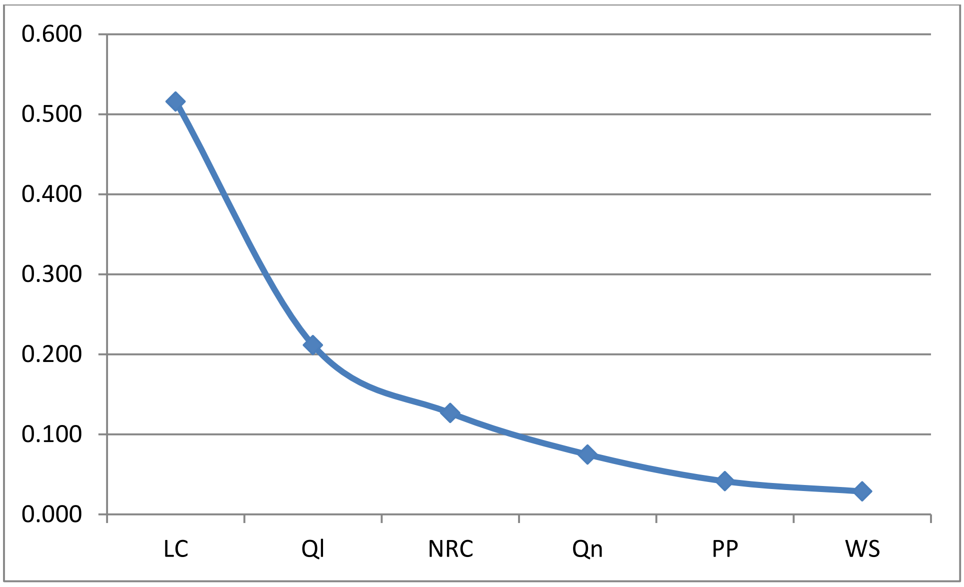


Figure 5.9 – Top Heavy Weighting Characteristic for AHP weightings in Compact Urban Authorities

5.3.2.3 Urban Authorities

For urban authorities, as seen in Table 5.11, the weighting is similar to that of a Top Heavy Characteristic. The *Net Running Cost* was found to be of the utmost importance, with a score of 41 out of 48 giving an importance rating of 85%, by a clear margin. This would lead to changes in the potential cost of providing a service having the largest impact on alterations on the selection of alternative. Where the authority must try to save as much money as possible, it is understandable that it comes to the forefront of urban authorities. When combined with the effect of progressively tighter budgets for authorities in Wales, the relative importance is increased.

The remaining five criteria were within the range of 29-23 (60% - 48% in importance ranking), indicating that they all have a similar impact on the decision making process for predominantly urban authorities. *Legislative Compliance* and *Quality of Recyclate* were found to be quite close in importance. This is understandable now that the quality of the recyclate collected forms part of the legislative selection process under the Waste (Wales) Measure (2010). Although not clearly defined as to what is accepted or not in terms of quality, its consideration must form part of the decision making process. In this case, they are both influential in selecting the appropriate solution alternative.

The impact, if transferred to the Analytic Hierarchy Process (AHP), of the five criteria excluding the *Net Running Cost*, would be low. The Top Heavy Characteristic in Figure 5.10 shows how these findings would be translated to AHP. The *Net Running Cost* criterion has a weighting of 0.518. Combined, the other five criteria only have a weighting of 0.482 and thus, individually, would not have an impact on the choice made.

Table 5.11 - Importance of Drivers and Barriers for an Urban Authority

										Total	Importance Rating
Net Running Cost (a)	5	5	5	6	4	6	4	6		41	85%
Legislative Compliance (b)	6	2	1	3	1	5	6	5		29	60%
Quality of Recyclate (c)	2	4	3	4	5	3	3	3		27	56%
Quantity of Recyclate (d)	4	1	6	1	6	2	2	2		24	50%
Public Perception (e)	1	6	4	5	2	1	1	4		24	50%
No. of Waste Streams (f)	3	3	2	2	3	4	5	1		23	48%

Table 5.12 - Matrix of Pairwise Comparisons for Urban Authorities based on findings

	a	b	c	d	e	f
a	1	5	6	7	7	8
b	1/5	1	3	4	4	5
c	1/6	1/3	1	3	3	4
d	1/7	1/4	1/3	1	1	2
e	1/7	1/4	1/3	1	1	2
f	1/8	1/5	1/4	1/2	1/2	1

ω (weighting)
0.518
0.207
0.122
0.058
0.058
0.037

CR = 0.049

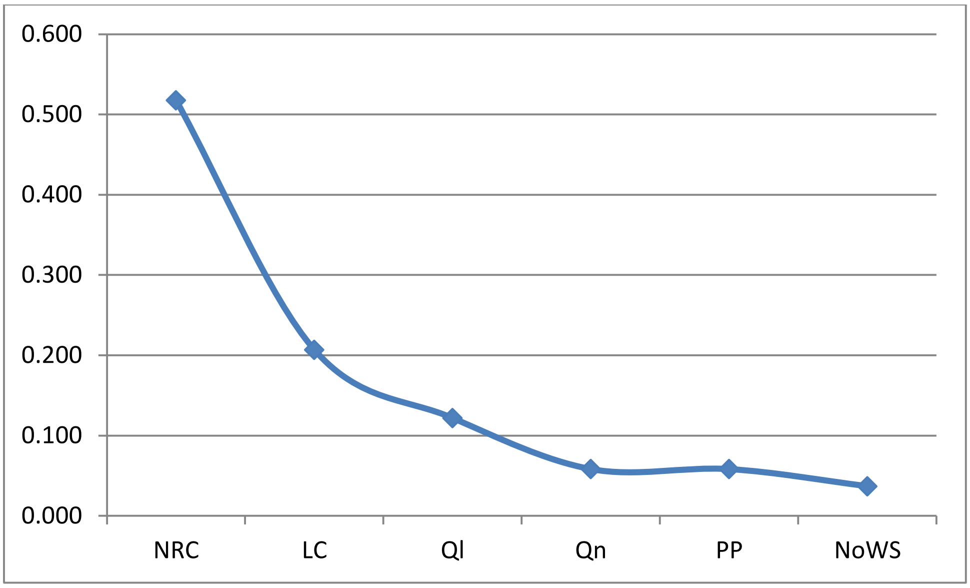


Figure 5.10 – Top Heavy Weighting Characteristic for AHP weightings in Urban Authorities

5.3.3 Summary

As previously stated, it can be seen from the above tables that the *Legislative Compliance*, *Net Running Costs* and *Quality of Recyclate* criteria consistently scored highest. Whilst this is expected, interestingly, the individual scores are quite erratic. As only four respondents returned the questionnaires for the rural authorities, the final importance rating is not as reliable as the other two. It would have been ideal if there were more returned, to see if a wider opinion corroborates the findings. For the compact urban authority, *Legislative Compliance* predominantly comprises 6's and *Quality of Recyclate* contains 4's and above, except for one 2. This places confidence in the outcome as the two most important criteria for these authorities. The remaining criteria sub-scores is much more varied. If there could have been more responses, this would again place further confidence in the remaining order.

For the urban authorities, the same is true for *Net Running Cost* as the highest importance ranking. The other five criteria contain a very mixed set of sub-scores. This explains the close values of importance ranking. There may be two reasons for this mix of sub-scores. Either what the criteria represent was not truly understood, thereby causing a mixed set of results or, more likely, the individual urban authorities really do place there importance on various criteria. This would again reinforce the fact that urban authorities have an eclectic mix of drivers for their choice of waste collection.

Even though it is on ‘instinct’, the respondents were the decision makers of their authorities. Their choices are what guide the selection of alternatives alongside decision making aids. By documenting their choices on a basic level, the validity of the choice of criteria can be confirmed.

5.3.4 Classification by Size

Using the same results from the questionnaires, the value judgements made by stakeholders in the LAs can also be classified by size. As mentioned previously, a small authority is one that has a population below 120,000 residents, a medium authority has between 120,001 and 140,000 and a large authority is classified as above 140,001 residents. The main aim of analysing LAs by virtue of their size is the variation in the collection ideals, judging by the mass that is collected. Although not a hard and fast rule, it can be assumed that the more people that are present in an authority, the more waste that needs to be collected.

5.3.4.1 Small Authorities

The priority order for small authorities can be seen in Table 5.13. Interestingly, the two criteria that are most important are *Net Running Cost* and *Quality of Recyclate* collected, with importance ratings of 73% and 71% respectively. This again brings up the issue of how to appease one of the criteria, without having a detrimental effect on the other. Is it possible to balance the needs of both these criteria? One could argue that they cannot, unless a third criterion joins these two, to mitigate the contrasting stand points of the impact that they have on the selection of an alternative. Also, it is understandable that *Net Running* Cost is most important as with a relatively lower absolute mass of recyclate to collect, their costs may increase per tonne collected.

Table 5.13 shows *Legislative Compliance* and the *Quantity of Recyclate* collected have the same importance rating, 63%. When their importance is evaluated alone, there is some continuity. The targets that are set in ‘Towards Zero Waste’ (WAG 2009) and the Waste (Wales) Measure (2010), ask for an increasing proportion of the waste that is collected to be segregated recyclate, year on year. This makes logical sense in the decision making process. Their values of 30 out of a possible 48 are slightly behind that of the previous two criteria valued at 35 and 34. This suggests that the small authorities take all four of these criteria to be of high importance. When evaluated in this way, a more complete picture forms.

The main focus is on bringing costs down. However, the increasing legislative pressure on LAs to collect a higher percentage of high quality recyclate each year, is a driver for the stakeholders. The barrier comes in the form of financial cuts each year and can be seen in Table 5.13, to form the axis of the small authorities' attention. The public's perception of how they do this comes low on their order of priorities. Could this be because the general consensus for these authorities is that in time, the public tend to accept whichever service is provided to them?

The *Number of Waste Streams* they collect comes last of all, and has a relatively similar score to *Public Perception*. This suggests that they are likely to try and recover the minimum of four streams required to achieve the goals that they are given. This may be because these small authorities are given smaller budgets, on account of having a smaller population. It is more probable that the *Number of Waste Streams* criterion features so low in the decision making process because they do not get the variety of waste streams in their authorities.Table 5.14 gives a likely matrix that would ensue based on the findings. Figure 5.11 is a graphical representation of the weightings. An almost Liner Weighting Characteristic is evident, except *Legislative Compliance* and *Quality of Recyclate* have very similar weightings with 0.129 and 0.121 respectively. However, *Net Running Cost*'s weighting of 0.403 would mean that it of a much higher importance than any other criterion.

Table 5.13 - Importance of Drivers and Barriers for Small Sized Authorities

										Total	Importance Rating
Net Running Cost (a)	6	6	6	2	2	5	5	3		35	73%
Quality of Recyclate (b)	5	4	4	6	4	2	4	5		34	71%
Legislative Compliance (c)	4	3	3	5	6	6	2	1		30	63%
Quantity of Recyclate (d)	5	1	5	3	5	4	1	6		30	63%
Public Perception (e)	3	1	2	1	3	1	6	4		21	44%
No. of Waste Streams (f)	2	2	1	4	1	3	3	2		18	38%

Table 5.14 - Matrix of Pairwise Comparisons for Small Authorities based on findings

	a	b	c	d	e	f
a	1	2	4	4	8	9
b	1/2	1	3	3	7	8
c	1/4	1/3	1	1	5	6
d	1/4	1/3	1	1	4	5
e	1/8	1/7	1/5	1/4	1	4
f	1/9	1/8	1/6	1/5	1/4	1

ω (weighting)
0.403
0.279
0.129
0.121
0.043
0.024

CR = 0.054

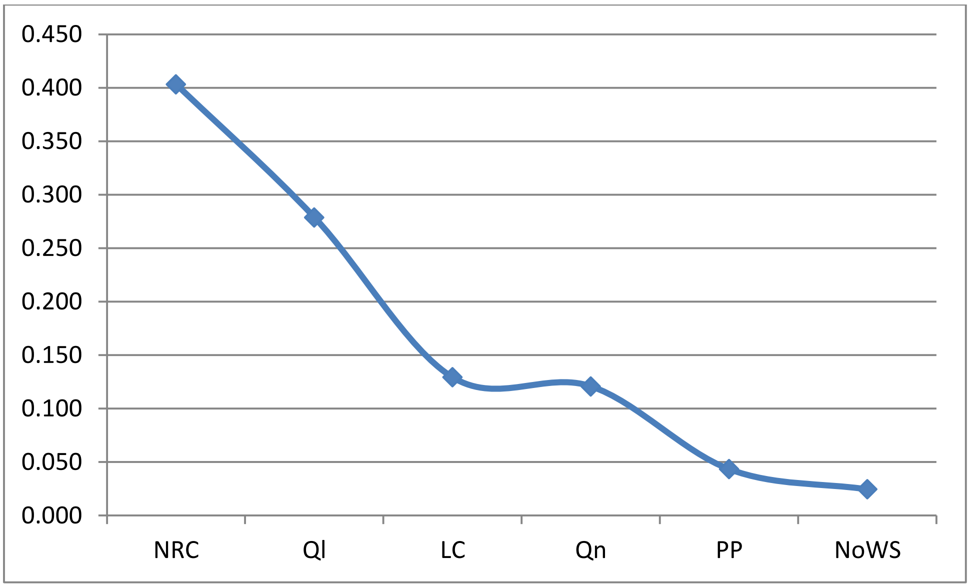


Figure 5.11 - Graphical Representation of Weightings for Small Authorities

5.3.4.2 Medium Authorities

For the medium sized authorities, Table 5.15 shows that the criteria are all very similarly weighted within the range of 20-29 out of a possible 42 giving importance ratings between 69% and 48%. Taking in to account all the authorities that responded, their importance is much more evenly distributed amongst the criteria. There is a slight split between three of the criteria compared to the other three giving a cross between a Split Weighting and Proximate Weighting characteristic. Similar to the opinions of the small authorities *Quality of recyclate*, *Net Running Cost* and *Legislative Compliance* are of main concern to medium sized authorities. The difference is that the *Quality of Recyclate* and *Net Running Cost* are of equal importance and *Legislative Compliance* is slightly less so.

However, the *Quantity of Recyclate* collected, the *Number of Waste Streams* and the *Public Perception* have a strong effect on the operations of these authorities. With the valuations being so close, they would have a significant impact on the choice of alternative. The reason for this is that those authorities that have a middling population size have many more variables to consider. Unlike the small authorities, they have more residents to consider, which may be from different ethnic backgrounds that do not traditionally recycle and more varied age (Emery et al. 2004) and unlike the other authorities, they have pockets of urban elements. They have towns that are spread out within their authority boundaries. This provides a challenge of itself, in that the collection method must be productive in these urban areas and also able to be translated to the areas that are more rural. This partly explains why the grouping of all six criteria is so close. With a diverse area to deal with, it can be difficult to identify one or two driving forces in the decision making process.

When the findings are weighted through AHP, there is a clear Split Weighting characteristic, with one anomalous weighting, *Legislative Compliance*. The top two criteria have force majeure with weightings of 0.309, as highlighted in Table 5.15, thereby stating they must equally be appeased to satisfy the decision maker(s) choice.

Table 5.15 - Importance of Drivers and Barriers for Medium Sized Authorities

									Total	Importance Rating
Quality of Recyclate (a)	6	4	4	2	4	4	5		29	69%
Net Running Cost (b)	5	3	5	1	5	6	4		29	69%
Legislative Compliance (c)	4	1	6	6	6	3	1		27	64%
Quantity of Recyclate (d)	3	5	3	3	1	1	6		22	52%
No. of Waste Streams (e)	1	6	2	4	2	2	3		20	48%
Public Perception (f)	2	2	1	5	3	5	2		20	48%

Table 5.16 – Matrix of Pairwise Comparisons for Medium Authorities based on findings

	a	b	c	d	e	f
a	1	1	2	4	5	5
b	1	1	2	4	5	5
c	1/2	1/2	1	3	4	4
d	1/4	1/4	1/3	1	2	2
e	1/5	1/5	1/4	1/2	1	1
f	1/5	1/5	1/4	1/2	1	1

ω (weighting)
0.309
0.309
0.193
0.084
0.053
0.053

CR = 0.0.11

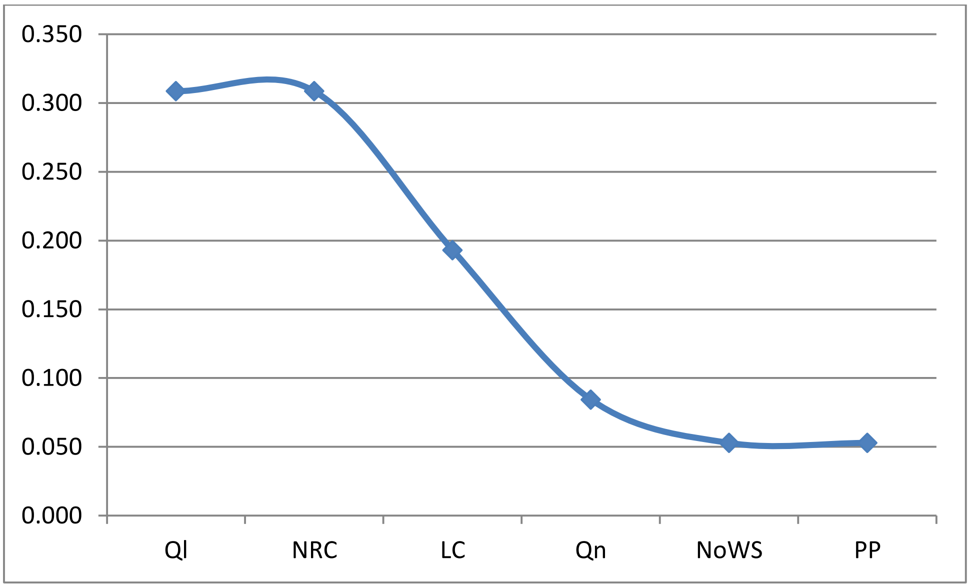


Figure 5.12 – Graphical Representation of Weightings for Medium Authorities

5.3.4.3 Large Authorities

For large authorities, the criteria were ranked as per Table 5.17, where there is a clear divide between two of the criteria and the remainder, giving a Split Weighting Characteristic. *Legislative Compliance* and *Net Running Cost* have significantly higher weightings with importance rating values of 92% and 72% respectively. It is unsurprising that these two have come out on top for the large authority. With a higher number of residents to cater for, invariably there is a larger service to deliver. The financial stress this puts on the authority, in relation to their budget, would be very important. With Legislative Compliance so closely weighted, the large authorities must also consider the difficulties similar to compact urban authorities. With the likes of Cardiff, Newport and Swansea authorities in this classification, the pressure is on these authorities to perform. The large authorities account for over half of the population of Wales. If they are not achieving the targets set out in Toward Zero Waste (WAG 2009), quality compliance and creating environmental benefit, then Wales as a whole, will suffer environmentally.

Quality of Recyclate, the *Number of Waste Streams* collected and *Quantity of Recyclate* collected gradually decrease as a set, below the first two criteria. Of notable interest is how low the *Quantity of Recyclate* criterion is considered at 42% importance rating. It must be a given certainty, in the eyes of the decision makers, that there will be a high quantity of recyclate placed out for collection by householders of their authorities. It has featured as being more important in the medium and small sized authorities. *Public Perception* comes lowest of all with a rating of 29% and most of the authorities considering it of least importance out of all the drivers and barriers. This reinforces the idea that they believe that the public will eventually accept a recycling scheme with time, without adversely affecting their quantity or quality collected.

Table 5.17 - Importance of Drivers and Barriers for Large Authorities

						Total	Importance Rating
Legislative Compliance (a)	5	6	5	6		22	92%
Net Running Cost (b)	6	4	6	3		19	79%
Quality of Recyclate (c)	3	3	3	5		14	58%
No. of Waste Streams (d)	4	5	1	2		12	50%
Quantity of Recyclate (e)	2	2	2	4		10	42%
Public Perception (f)	1	1	4	1		7	29%

Table 5.18 - Matrix of Pairwise Comparisons for Large Authorities based on findings

	a	b	c	d	e	f	ω (weighting)
a	1	3	5	6	7	9	0.441
b	1/3	1	5	6	7	8	0.299
c	1/5	1/5	1	2	4	6	0.116
d	1/6	1/6	1/2	1	2	4	0.072
e	1/7	1/7	1/4	1/2	1	3	0.046
f	1/9	1/8	1/6	1/4	1/3	1	0.025

CR = 0.072

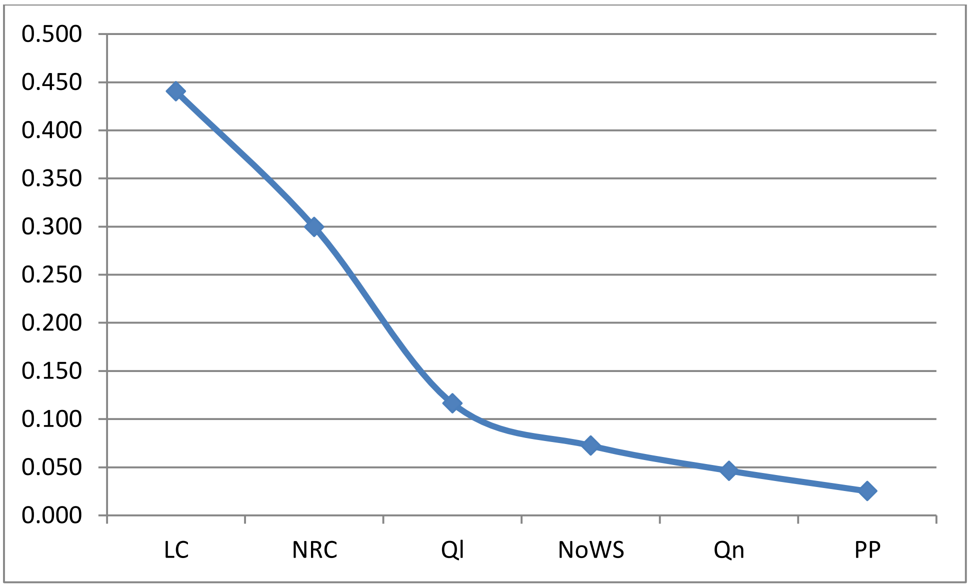


Figure 5.13 - Graphical Representation of Weightings for Large Authorities

5.3.5 Summary

Overall, when authorities are classified by virtue of their type, the three criteria that are once more consistently considered as the three most important are *Quality of Recyclate*, *Legislative Compliance* and *Net Running Cost*. However, the discrepancy between these three and *Public Perception*, *Quantity of Recyclate* collected and the *Number of Waste Streams* collected is not substantial. Figures 5.14 and 5.15 show an overlay of the results above for comparison.

Of particular interest is the low ranking of importance of *Public Perception*. The collection of householder's food waste, recyclate and residual waste is a service that relies on the public to participate. It would be rational to assume therefore, that if the scheme was not accepted by the public it would be detrimental to the collection targets to be achieved. However, unanimously, the public perception and acceptance of a scheme is very low on the order of priorities for councils. The presumption from this result is that experience shows this to not be the case and whatever scheme the LA decides to use, would be accepted in the long run.

Equally, the *Number of Waste Streams* ranks very low, suggesting that the authorities are most likely to collect only what is necessary. The biggest discrepancy is the importance of *Legislative Compliance*. A large, urban authority will consider it to be of most importance, whereas a small, rural authority will have it low on their importance.

Quality of Recyclate is the most unpredictable of all the criteria in determining how important it is. The closest link can be found between large and compact urban authorities, who place it low in importance. With exception of urban classification, the *Net Running Costs* criterion was of high importance for all classifications of authority.

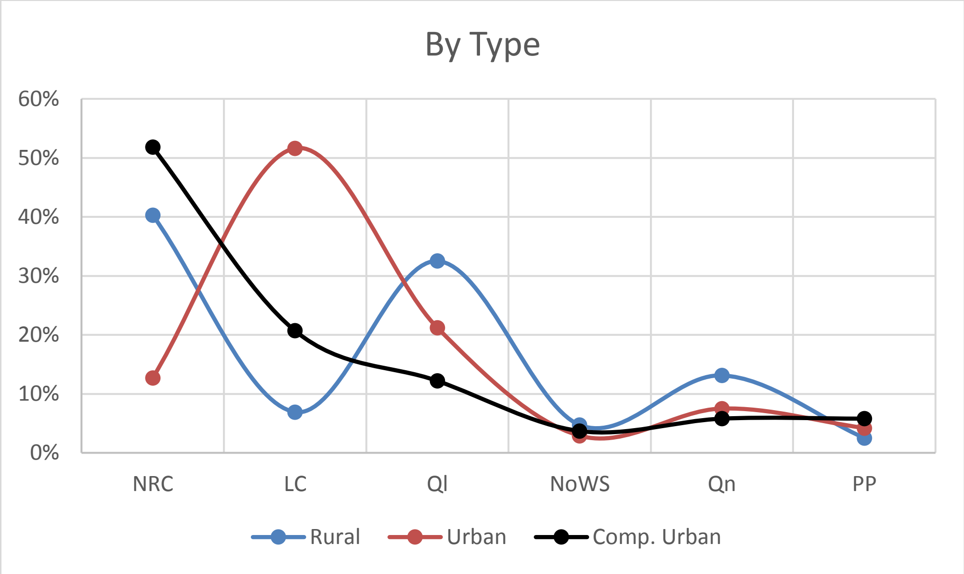


Figure 5.14 – Overlay of the results by type

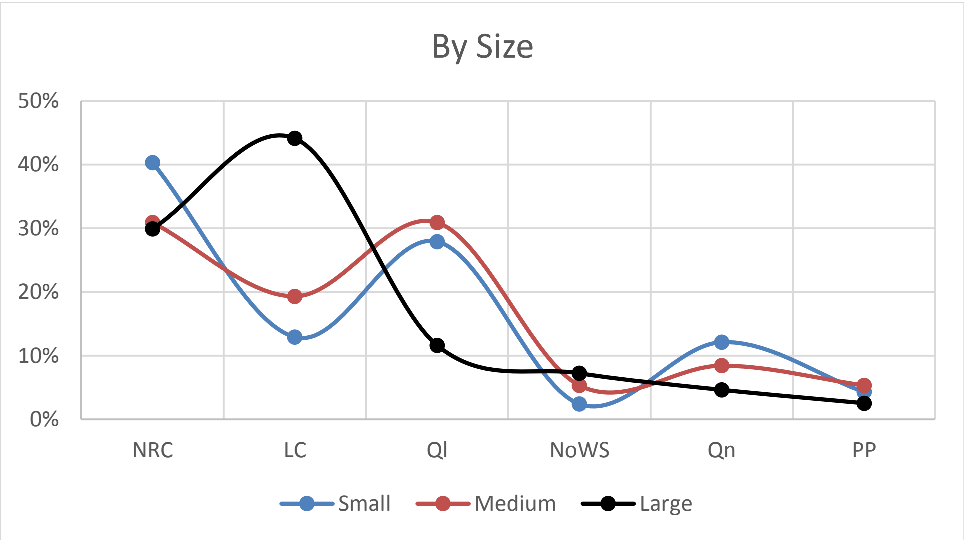


Figure 5.15 – Overlay of the results by population size

Although authorities by classification and characteristic broadly give agreement when the individual scores are scrutinised, it can be seen that these are more erratic than the overall decisions. This highlights the fact that the decision making process is a highly personal one. Each authority may share similar traits with others, but is ultimately unique. It follows that a one size fits all approach cannot be the perfect answer.

This reinforces the notion that a decision making process that is well documented is required. To clearly document these and be able to discuss which drivers and barriers truly most affect the choice taken by stakeholders, enable a logical process. At the very least, it is needed to select the criteria that are of utmost importance to a LA when deciding on a waste management scheme. The next logical step would be to ask the authorities to rank the solution alternatives in the same way. However, at the time, this was not possible, as the consideration required is very specific and requires a lot of time for deliberation, which this author found that authorities were unwilling to do.

By mixing characteristics with classifications, scenarios can be built to represent the most likely outcomes form Local Authorities, dependant on size, type and decision making weightings. The analysis can give suggested alternatives depending on the criteria that are most important to the authority, hence the scenarios can be employed. Any combination of importance order of the six criteria, in theory, could come to fruition. By examining these combinations and relating their effect to rural, urban, compact urban, small, medium and large classifications, the decision making process can be clarified.

The interaction of the criteria can be examined in these situations and can also be carried out with the possible solution alternatives. Rather than second guessing the exact weightings that may come from a case study, the classifications can be used to give standardised outcomes. This has been suggested earlier, but more in depth analysis of the subtle differences is now carried out. In the main, this is done by using two of the drivers and barriers in a Split Weighting Characteristic e.g. *Net Running Cost* and *Public Perception* together as the highest weightings. What would be the likely issues concerned? What effect does this have on differing size and type of authorities? Does it make more sense if there is a third criterion in the Split Weighting Characteristic? How could it affect the choice of solution alternative?

Following on from this, how is the decision making process affected if the weightings are proximate? The sub-criteria become more important and can also be compared and evaluated at the same time and as will be seen, in some scenarios. How do they affect the choice of the solution alternative when their weights vary and if the parent criterion has a low or high weighting?

5.4 Drivers and Barriers Scenario Setting

Setting the scenarios will be done in the following way. The criteria from the drivers and barriers will be taken in tandem or in groups. In each situation, two criteria will be put forward in a Split Weighting Characteristic and the various characteristics will be applied. They are studied from the perspective of each classification giving the various scenarios. In this way, the likely effect and reasoning can be studied. This will then be applied to the classifications, by type and/or size. A third criterion may be included to better argue the reasoning why the first two may be selected as the two most important. A suggested solution alternative may be given in each case, where possible. In some cases, there is not a clear distinction in the choice that can be made and the process would need to be applied in a case study to give a suggested solution alternative. The results are then be compared against the Case Study Authority and whether the theory aligns with the practical application of the decision making process.

The study showed that the *Legislative Compliance*, *Net Running Costs* and *Quality of Recyclate* criteria are consistently the three most important. Therefore, the main consideration will be given to when two of these three criteria are highest in the following scenarios. The nuances in the decision making process of the remaining drivers and barriers are considered. Each criterion can affect authorities in differing ways, leading to different selections of solution alternatives and the effects that this has on their selection. It would be remiss not to consider the effects of a Split Weighting characteristic scenario involving the other criteria as most important. For completeness, these scenarios will also be considered and evaluated.

In addition, the interaction of the two suggested, most important criteria, can have significant issues from different aspects. It may be the choice of the solution alternative is of most concern, or it may be that the size or type of authority is the main point of comparison. The following sections create a total of sixteen scenarios. Firstly, the effect of a Proximate Weighting Characteristic is observed. The remaining fifteen sections examine the reasoning why two criteria would be deemed most import, the effect on the likely selection of solution alternative and the effect on authorities depending on their classification.

5.4.1 Proximate Weighting

If the ***Drivers and Barriers*** have a Proximate Weighting characteristic the criteria are deemed to be of similar importance. Their effect on the selection of solution alternative is nullified. The emphasis is then placed solely on the alternatives themselves and how they achieve each criterion in the opinion of the stakeholder(s). The single alternative that best achieves *all* criteria will be the suggested outcome.

It is possible to suggest that a commingled collection would be preferred by compact urban and urban authorities. Only one receptacle is needed and, assuming that urban and compact urban areas have a high majority of terraced housing and flats for example, the space constraints would dispose them to this method. This type of collection offers much more flexibility in the provision of the service at a relatively lower cost than changing a Kerbside Sort scheme (KSS) too.

A rural authority may prefer a KSS collection owing to the relative space and non-reliance on a Materials Recycling Facility (MRF) being available. However, the decision will be solely based on the qualitative and quantitative data provided by the authority. Also, the choice would heavily rely on whether a MRF is available for use for an authority. Where it is, there may be a preference for commingled collection. Where there isn't, then a KSS collection becomes more attractive. Therefore, no meaningful suggestion for the choice of solution alternative can be made in terms of the classification of authority.

5.4.2 Net Running Costs & Legislative Compliance

According to the previous data, these are the most obvious choice of criteria for high priority. It is common knowledge that the delivery of a service must be as cheap as possible. The continued cut backs in funding provided by the Government to LAs and pressure from the public to keep costs down are combined drivers for the service to be as cheap as possible. Therefore, costs are the likely to be the main centre of attention.

By adhering to legislation, it may not always be the case that the cheapest option can be perused. Again, there are many variables to consider for the cheapest option. Let it be assumed that the LA contract out the sorting of waste/recyclate and is standardised i.e. not a cost concern. For the cheapest collection, a one-type bag collection would be the easiest and best choice. Operatives need not spend any time in the inspection of waste or for any other matter, allowing for a particular route to be covered in a short period of time. This would be the cheapest option for collection. However, Waste Regulations (Waste (England and Wales) Regulations 2011) do not allow this. It stipulates that glass, metal, paper and plastic must be collected separately. Therefore, the cheapest collection cannot be pursued blindly. It therefore acts as a barrier in this Split Weighting characteristic.

Currently, LAs do not adhere to this method of thinking. The penalties associated with non-compliance are low, to the point of not being adhered to. These penalties, financial or otherwise, are not stringent enough to be detrimental to a collection method and/or are not enforced. In actuality, Cardiff Council and Rhondda Cynon Taf Council were due to pay a combined fine of £1.3 million, for non-compliance with achieving recycling targets. They were spared the fine due to demonstrating they intend to improve their figures (Moore 2015). Once examples such as this stop occurring, the LAs will change their decision making methods and subsequently their methods of collection.

This example is simplified dramatically and only occurs if all other variables are ignored. From a cost perspective, if the sorting of waste is contracted out, there is still an effect on the *Net Running Cost* criterion. The LA must pay a third party for the service of separation and processing, which lead to the inclusion of the *Contract/Tender Cost* sub-criterion. All the sub-criteria must be evaluated to gain a true understanding of the priorities for *Net Running Cost*. This supports the need for a decision making process to allow for barriers that affect the decision undertaken.

Any changes in legislation may require changes to the service provided. In this way, a commingled collection may be the most obvious choice for a LA. It provides the flexibility to be able to change the streams that are collected, whilst only requiring a relatively small outlay (when compared to fleet/equipment changes needed in a KSS collection) in the release of promotional material.

For a small authority, this is less of an issue. If Net Running Costs are high on their priority, then a change in equipment is less in cost when compared to that of a large authority, due to less households being served. However, the cost of fully changing a collection method for small, medium or large authorities, would still be higher when compared to that of releasing promotional material to change the streams collected or to achieve an increased target. The same applies to authorities when they are classified by type.

For the above reason, the expected outcome for selection of alternative would be a commingled collection. The argument is strengthened if *Quantity of Recyclate* or *Number of Waste Streams* collected joins as the third criterion in a Split Weighting characteristic, as commingled collections perform better at achieving these criteria (WYG-Environment 2012).

5.4.3 Net Running Costs & Quantity of Recyclate collected

If there is a Split Weighting characteristic where *Net Running Cost* and *Quantity of Recyclate* are the two most favoured options, the decision is clear. As well as providing the service within budget, the decision is to focus on reducing the cost per tonne of recyclate collected. An increase in the quantity of recyclate collected, with maximal cost suppression, will help to keep the cost per tonne collected down. For a compact urban authority, these two criteria complement each other. The routes travelled will be less than the other two classifications by type and have more recyclate in a more compact area. For urban authorities, the cost increases for the collection of the same mass of recyclate and for rural authorities it becomes more still (Waste Awareness Wales and AEA 2011). This is a similar principle to economies of scale. In any industry economies of scale is the inverse relationship between cost of production and the per-unit fixed cost, i.e. the greater the number of units produced, the smaller the cost per unit is. For waste collection, the less distance required to travel and time taken to collect a specified mass of recyclate, the cheaper the collection will be due to less fuel usage and a lower wage bill for operatives. Therefore, for a compact urban authority with large population, the cost per tonne of recyclate collected will be less than that of a rural, small authority, when taking into account the *Work Force* and *Fleet* criteria, which predominate the influence of *Net Running Cost*.

The question is, which is more important to the authority? If *Quantity of Recyclate* is of more importance, then it would be expected that an authority will place a higher significance than usual on the *Advertising, Promotion and Enforcement (APE)* sub-criterion of *Net Running Costs*. With a higher level of knowledge, and education from a young age, of what can be placed in to recycling receptacles by householders, the quantity of recyclate collected will be higher (Maddox et al. 2011). Thus validating the decision of these two criteria being most important. This holds true regardless of the selection of the solution alternative.

If *Net Running Costs* and *Quantity of Recyclate* are regarded as the most important, it would also be expected that *Quality of Recyclate* would be of higher importance too. A Split Weighting Characteristic with these three is likely. For the costs to be kept low with a high quantity of recyclate, the costs of reprocessing would need to be kept low. A higher quality of recyclate will achieve lower reprocessing costs, connecting the three criteria in importance.

The above means that the likely selection of alternative could go either way. There is an argument that commingled collections tend to create a higher rate of capture than kerbside sort collection schemes (WYG-Environment 2012). In addition, more households can be covered in the same amount of time than a kerbside sort scheme thereby increasing the likelihood of being able to collect more recyclate in a shorter period of time. It can be argued that the reprocessing is of no concern to the LA, if it is contracted to a third party and thus does not enter into the decision making process, strengthening the choice of a commingled collection. But this must have been agreed and the reasoning documented before embarking on the process.

On the other hand, it is argued by WRAP (WRAP 2008) that with a vastly reduced amount of reprocessing required from recyclate collected through a kerbside sort scheme, the actual time taken to achieve a 'final product' that can be used, is very similar. Furthermore, the quality of the recyclate tends to be lower from a commingled collection, especially in relation to paper (Miranda et al. 2013). Thus, where a 3-criteria Split Weighting characteristic is assumed, with the *Quality of Recyclate* criterion as highest importance, then the KSS scheme may be the chosen alternative. This highlights the necessity to agree on the boundaries and assumptions taken, before the decision making process is undertaken. If this is not clear, then there can be uncertainty in the final choice because counter arguments can arise. The assumptions that are made at the very beginning of the process must be clearly defined and justified.

5.4.4 Net Running Costs & Quality of Recyclate collected

As stated previously, if *Net Running Cost* and *Quality of Recyclate* were to be chosen as the two most important criteria, there exists a slight dichotomy. For the quality of the recyclate collected to be high, significantly more investment is predominantly required in labour or infrastructure. The sorting of waste manually is the most effective way of ensuring a high quality of recyclate. With enough man power, all waste can be sorted perfectly. In a KSS scheme, this is done on the routes, with more operatives present than in a commingled kerbside collection. They inspect all recyclate before placing it in to the stillage vehicle. When compared to a commingled collection, the sorting is carried out by a mix of plant and human operatives. This gives a varying degree of quality. There is no minimum quality standard as DEFRA have allowed the market to determine the standards required (Date 2014a). Regardless of the choice of alternative, the net running costs are driven up, with respect to all the sub-criteria, if quality of recyclate is ensured.

Therefore, to bring the two closer, the analysis for these two criteria being of high importance is likely to be associated with a third, namely *Legislative Compliance*. Regulation 13 of the Waste (England and Wales) Regulations (2011), requires a certain standard of quality from the recyclate collected. Whilst *Net Running Cost*, in this situation, is of high bearing, the likely combination with *Quality of Recyclate* would be down to being 'forced' to have to consider it. By adhering to legislation, and thereby believing the *TEEP Regulations* sub-criterion to be most significant, it is logical then that *Quality of Recyclate* and *Net Running Cost* criteria can both be considered high in importance. This would likely show in a Split Weighting Characteristic with these three being much higher than the other three criteria.

When considering the choices by classification of authority, this scenario is a likely one for a compact urban authority, which will struggle to ensure the quality of the recyclate they collect. With a diverse range of housing their preference would be for a flexible service that accommodates all types. A commingled collection would be the most probable outcome for them with an emphasis on the *APE* criterion, to aid in achieving a high quality of recyclate collection. For urban and rural authorities, keeping costs as low as possible is likely to be more of a cause for concern. When classified by size, this has no direct bearing on the quality of recyclate. But as the size increases, so do the relative costs incurred. Therefore, a large authority will place more importance on the *Work Force* and *Fleet* sub-criteria than a small or medium authority. The small authority will most likely be able to spend more on *APE* to ensure a higher quality of recyclate.

The likely choice of solution alternative is very much dependant on the type of authority and the assumptions made. It could be that KSS is the overwhelming choice for the quality of recyclate it achieves. It is dependent upon the description of quality and what is acceptable to the authority, as to whether the KSS collection is preferred over a commingled collection.

5.4.5 Net Running Costs and Number of Streams collected

This scenario is very unlikely to occur in practice. It is more likely to be plausible if there was a Linear or 3-criteria Split Weighting characteristic alongside the *Quantity of Recyclate* collected criterion. With more streams collected, a higher quantity of separate recyclate may be possible. In theory, for an increased Number of Streams collected in a recyclate scheme, a commingled collection would be most suited over a KSS scheme.

There is a small community in Japan, Kamikatsu, that must sort their waste in to 34 categories to be recycled (Harrabin 2008), showing that it *is* possible to collect a large number of streams. However, would this be practicable in an urban setting and would it be accepted? Highly unlikely and this is an extreme illustration. However, if for example, an authority wanted to collect seven or eight streams of recyclate, would it be cost efficient to give every house that many receptacles? Would the householders be able to store that many boxes or bags in their house? This kind of option would require a large initial outlay, thereby driving up the cost of providing the service and contradicting the emphasis of this scenario. No matter the classification of authority, if *Net Running Cost* and *Number of Streams Collected* were the two most important criteria, a commingled collection would be the most likely choice of alternative.

5.4.6 Net Running Costs & Public Perception

The selection of *Net Running Cost* and *Public Perception* criteria as the two most important criteria is favourable in the eyes of an authority for publicity purposes. The likelihood is that a method of recyclate collection that has the lowest running cost is most likely to be accepted by the public. Waste collection services are one of the most visible council led services to the public. A saving in the delivery of such a service will create a possible *expectation* that council tax will decrease or the public will see a financial benefit elsewhere.

If *Net Running Cost* and *Public Perception* are chosen as the two most important criteria in the decision making process, then there is a high likelihood that *Advertising, Promotion and Enforcement* is considered important in the sub-criteria of *Net Running Cost*. Where there are savings made on the delivery of service, the council will want to advertise this, if the public's perception and acceptance is important to them. Also it has been suggested by Emery et al. (2004) and AEA (2011), that residents would like to receive more feedback. Furthermore, the study revealed that engagement with residents over participation in recycling and re-use initiatives, is one of the services most hit by austerity measures. The more empowered and included they feel in the betterment of their area and the environment, the more they are likely to participate.

In reality, this is an unlikely scenario to occur, based on the information gathered in Section 5.3 *Public Perception* was found to be of the second lowest importance in general, whilst *Net Running Cost* criterion was always near the top, regardless of size or type of authority. However, it is a possibility that the *Quantity of Recyclate* criterion would complement the choice of these two criteria, in a 3-criteria Split Weighting characteristic. It is rational to assume that with public acceptance and approval of a recyclate collection scheme, they are more likely to participate and therefore more recyclate may be collected.

Due to the back and forth nature of which is the most suitable method of collection (letsrecycle 2013), it is near impossible to predict which alternative would be the most likely outcome in this situation. Firstly, it depends upon the stakeholders within the authority. Only a survey of householders in the given authority could determine whether a KSS or commingled collection would be preferable, as well as checking the cost effectiveness of a change. Equally, in terms of net running costs, it cannot be mutually agreed across the sector as to which method of collection is cheapest to run. All of these reports have differing views depending on the criteria that are taken in to account. It is therefore up to the decision maker(s) to decide the relevant assumptions.

5.4.7 Legislative Compliance & Quantity of Recyclate collected

If *Legislative Compliance* and the *Quantity of Recyclate* criteria were considered key in selecting the best method of waste collection, the targets that are set out in legislation (Welsh Government 2010) will be high on the priorities for a LA. This means that the *Toward Zero Waste* sub-criterion of *Legislative Compliance* will likely have a Top Heavy Weighting characteristic, when pairwise compared with the other sub-criteria. The Toward Zero Waste targets outline step percentage increases year on year, in the collection of recyclate as a whole of waste collected. Therefore in this scenario, the authority is placing a heavy emphasis on exceeding the targets set by Welsh Government.

However, the remaining sub-criteria of *Legislative Compliance* cannot be ignored. If, as in the example in Figure 5.16, *Legislative Compliance* has been given the highest weighting, achieving legislative demands is the highest priority for the authority. Depending on the emphasis placed on these sub-criteria, they can influence the choice of alternative. Figure 5.16 shows *Legislative Compliance* to have a weighting of 0.4405. The sub-criteria in this example have a Linear Weighting characteristic. As there are only four sub-criteria under scrutiny, the weighting of *TZW* is 0.467, translating to a global weighting of 0.2056. Therefore, the option that achieves the percentage targets laid out in 'Towards Zero Waste' has the highest weighting, followed by the remainder. The effect the other sub-criteria have can be seen in the global weightings. The values, none of which are above 0.0262, have a relatively small impact when compared to those of options 1-4 under *TZW*. Whilst they cannot be discounted, some have a negligible impact.

Table 5.19 - Linear Weighting Characteristic for the weightings of sub-criteria for *Legislative Compliance*

	TZW	Fin. Pen	TEEP	Env. Ben	ω (weighting)
TZW	1	2	3	4	0.467
Fin. Pen	1/2	1	2	3	0.278
TEEP	1/3	1/2	1	2	0.160
Env. Ben	1/4	1/3	1/2	1	0.095

CR = 0.011

1		Best Waste Collectio						
2		Recyclate, Reasidu						
3		Legislative Compliance				No. of Streams	Quantity	
4		TZW	Fin. Pen	TEEP	Env Ben			Work Forc
5	Option 1	0.0723	0.0233	0.0127	0.0082	0.1053	0.0409	0.0106
6	Option 2	0.0496	0.0172	0.0096	0.0084	0.0722	0.0281	0.0073
7	Option 3	0.0328	0.0262	0.0216	0.0072	0.0478	0.0186	0.0048
8	Option 4	0.0214	0.0163	0.0058	0.0075	0.0312	0.0121	0.0031
9	Option 5	0.0139	0.0176	0.0085	0.0024	0.0203	0.0079	0.0020
10	Option 6	0.0092	0.0086	0.0034	0.0037	0.0134	0.0052	0.0014
11	Option 7	0.0063	0.0130	0.0090	0.0045	0.0092	0.0036	0.0009
12		0.2056	0.1223	0.0706	0.0420			0.0302
13		0.4405				0.2995	0.1163	
14		1.0000						

Figure 5.16 – Extract from the programme – weightings of sub-criteria of *Legislative Compliance*

Whenever Legislative Compliance has a high weighting, the alternative that best meets all legislative conditions will be the most opportune choice. When paired with *Quantity of Recyclate* then the method that collects the most recyclate, whilst appeasing legislation is the best outcome.

5.4.8 Legislative Compliance & Quality of Recyclate collected

In the same way that a Split Weighting characteristic of *Legislative Compliance* and *Quantity of Recyclate* would create a focus on the sub-criteria, the same is true of *Legislative Compliance* and *Quality of Recyclate*. Regulation 13 of the Landfill (England & Wales) Regulations (2011) states that metal, plastic, paper and glass must all be collected separately. This is to ensure a higher quality of recyclate collected at kerbside. It follows that if these two are considered the most important two criteria in the ***Drivers and Barriers***, the *TEEP Regulations* sub-criterion will have a high value weighting when pairwise compared to the relevant sub-criteria.

This will have a direct effect on the selection of a solution alternative. The most likely alternative to be selected in this case, regardless to classification of authority, is a KSS scheme. The nature of this collection follows Regulation 13, where four separate receptacles can be used to collect each stream. The quality of the recyclate will be high, on account of lower potential for contamination e.g. broken glass with paper. However, there is the possibility that should these two criteria be considered most influential on the decision, a commingled collection may be used.

Commingled collection of recyclate appeases Regulation 13, as it can be used to collect the four streams separately. The recyclate is subsequently sorted. If the authority could prove that the recyclate can be separated into the four streams, with a high standard of quality, commingled kerbside collection could be a viable choice. In practice, this is doubtful. It is undeniable that having separate receptacles for separate streams will reduce the likelihood of contamination thereby giving high quality recyclate. If the findings from Section 5.3 are applied, a 3-criteria Split Weighting characteristic are to be used, the *Net Running Cost* criterion would be involved. The dynamic changes little. If there is no MRF in the vicinity of the authority, the cost of setting one up or transporting to the nearest (providing the quality can be assured), will be much higher than setting up a new KSS scheme.

5.4.9 Legislative Compliance & Number of Waste Streams collected

In a scenario where *Legislative Compliance* and *Number of Waste Streams* are the two most important, the authority would be looking to maximise the number of streams they collect in the recyclate. This is another unlikely scenario to occur. To achieve legislation, only the minimum of four streams needs to be collected. Therefore these two are unlikely to be seen together as the two most import criteria in the ***Drivers & Barriers*** layer. If *Quantity of Recyclate* collected were to join in a 3-criteria Split Weighting or Linear Weighting characteristic, it may be more realistic.

By trying to collect more recyclate, one method of achieving this is to collect more streams. This involves less work for the householders. They can have confidence that if unsure about whether an item can be recycled, the more likely that it can, they are more likely to place it in the recycling receptacle. For all classification of authorities, a reduction in residual waste could be seen in this scenario. This can help them keep to the national landfill allowance targets set in The Landfill (Maximum Landfill Amount) Regulations (2011) further justifying the high importance of *Legislative Compliance*.

It would be expected that *TZW* would be the most important of the sub-criteria of *Legislative Compliance* in this scenario, as per Figure 5.17. The Split Weighting characteristic can be seen with weightings of 0.4043 and 0.3471 for the two criteria. The solution alternative weightings from *Number of Waste Streams* is a direct result of pairwise comparisons and divided accordingly. However, due to sub-criteria under *Legislative Compliance*, the impact of its weighting is split between 28 weightings rather than 7. Figure 5.17 shows *TZW* having a higher impact than the remainder, highlighting this.

1		Best Waste Collection Method								
2		Recyclate, Reasidual, Food								
3		Legislative Compliance				No. of Streams	Quantity	Running Cost		
4		TZW	Fin. Pen	TEEP	Env Ben			Work Force	Fleet	APE
5	Option 1	0.0664	0.0395	0.0228	0.0135	0.1220	0.0390	0.0102	0.0064	0.0039
6	Option 2	0.0455	0.0271	0.0156	0.0093	0.0837	0.0267	0.0070	0.0044	0.0027
7	Option 3	0.0301	0.0179	0.0103	0.0061	0.0554	0.0177	0.0046	0.0029	0.0018
8	Option 4	0.0196	0.0117	0.0067	0.0040	0.0361	0.0115	0.0030	0.0019	0.0012
9	Option 5	0.0128	0.0076	0.0044	0.0026	0.0235	0.0075	0.0020	0.0012	0.0008
10	Option 6	0.0085	0.0050	0.0029	0.0017	0.0156	0.0050	0.0013	0.0008	0.0005
11	Option 7	0.0058	0.0035	0.0020	0.0012	0.0107	0.0034	0.0009	0.0006	0.0003
12		0.1888	0.1122	0.0648	0.0385			0.0289	0.0182	0.0111
13		0.4043				0.3471	0.1108	0.0692		
14		1.0000								

Figure 5.17 – Extract from the programme – *Legislative Compliance* and *Number of Waste Streams* Scenario, with *TZW* showing high importance

5.4.10 Legislative Compliance & Public Perception

This is again another unlikely scenario to take place in reality. The suggestion for an authority to consider absolute legislative compliance and the public's perception could be a very difficult one. The LA may have to take action that is against the public's want. If this situation arose, which direction does the authority follow, if these two criteria have been rated as equally (or closely) important?

On the other hand, it could be argued that the public will always be in favour of the LA achieving legislation. The cost of non-compliance could be high. If the public were to assume that non-compliance with EU and UK legislation could result in a raise in cost to them or a diminished service, then they may be in favour of an authority achieving legislation come what may.

In terms of a suggested solution alternative or the effect of classification, there is little influence from these two criteria, unless it is explicitly stated in legislation in the future or a survey of preference of householders.

5.4.11 Quantity of Recyclate & Quality of Recyclate

A Split Weighting characteristic that has *Quantity of Recyclate* and *Quality of Recyclate* as the most important criteria has an interesting dynamic. The message is clear, at any cost, regardless of legislation and public opinion, attain as much recyclate as possible, as cleanly as possible. Where cost is not an issue, then a hybrid of commingled collection and KSS could be used. With a close inspection of a two stream collection the quantity received could be kept high, through ease of use to householders. An example may be with paper collected separately from the other three streams (collected in one receptacle). The most common contamination problem for paper is glass, metal, liquid and food residue (Miranda et al. 2013). By keeping paper separate, which is usually the highest percentage of recyclate by mass, a high quality can be maintained.

This solution could work well for rural and urban authorities. It is less likely for compact urban authorities. If it is assumed that these authorities are mainly comprised of a city, evidence suggests (Waste Awareness Wales and AEA 2011) that people of this classification want as little variance as possible. If the authority is most interested with quantity and quality of recyclate, then participation is crucial and appeasing residents can achieve this.

5.4.12 Quantity of Recyclate & Number of Streams

The partnership of these two criteria as predominant, are complimentary. At a basic level, the more types of waste that the public can place into their recyclate, the more likely they are to keep the quantity entering these receptacles high. Although unlikely as the most important two criteria, it may be for an authority that at the time has a low recycling rate. It becomes an important factor to up the quantity of recyclate that they collect. The decision maker(s), in this scenario, evidently believe that by increasing the number of streams they collect, the higher their quantities will be.

Taking in to account a Split Weighting characteristic, it becomes important if there is a third criterion in the top half. If the third was to be *Legislative Compliance*, the TZW targets are at the forefront of concern. It would be expected that emphasis would be made on this sub-criterion, as well as *Quantity of Recyclate* and *Number of Waste Streams*, as seen in Figure 5.18. This shows the main contributors, as outlined, and the influence they have when compared to all the other criteria, upon the choice of alternative. In this case, solution alternative Option 1 is the best outcome. Of its final weighting, 0.352, the three criteria outlined contribute 0.2811 to this value of importance. The *Quantity of Recyclate* and *Number of Waste Streams* criteria contribute 0.2473, the majority.

Judging by the figures, as per StatsWales (2014), the type of authority that is in need of increasing the quantity of recyclate they collect is compact urban. This provides the basis of the classification of authority that may come out with a decision that places most emphasis on these two criteria. The discrepancy, as at 2014, is only very slight as their overall rate is 52%, only 2% below the average across Wales.

If the third criterion were *Net Running Cost*, one would expect to see an increased emphasis on the *Advertising, Promotion and Enforcement (APE)* criterion, circled in yellow in Figure 5.19. To ensure a higher participation in a recycling scheme, the more educated the public are with regards to what they can and cannot recycle (and reuse), the higher the quantity of recyclate that can be achieved (Maddox et al. 2011). In a similar manner to TZW criterion, this would contribute more and have more influence in the selection of the alternative.

The paradox is that *APE* is based on quantitative data. Therefore it is unlikely to have a large impact, as the expenditure here is normally substantially lower than for *Work Force* and *Fleet*. The decision maker(s) could therefore go back in to the programme and adjust the pairwise comparisons manually, to come in line with the scenario.

For the suggestion of a suitable solution alternative, a commingled scheme would be the most appropriate. This type of collection provides the flexibility of being able to collect new streams with little change in the method of collection. Publicity to announce what new additions may be disposed of in the 'usual manner' means less disruption to service, less confusion in changing receptacles and also a lower cost to the authority.

Best Waste Collection Method

Recyclate, Reasidual, Food

	Legislative Compliance				No. of Streams	Quantity	Running Cost					Public Perception	Quality	Weightings for Alternatives
	TZW	Fin. Pen	TEEP	Env Ben			Work Force	Fleet	APE	Contract	Rejects			
Option 1	0.0338	0.0113	0.0068	0.0042	0.1176	0.1297	0.0095	0.0060	0.0036	0.0022	0.0014	0.0137	0.0118	0.352
Option 2	0.0232	0.0078	0.0047	0.0029	0.0806	0.0889	0.0065	0.0041	0.0025	0.0015	0.0010	0.0094	0.0081	0.241
Option 3	0.0154	0.0051	0.0031	0.0019	0.0534	0.0589	0.0043	0.0027	0.0017	0.0010	0.0006	0.0062	0.0053	0.160
Option 4	0.0100	0.0033	0.0020	0.0012	0.0348	0.0384	0.0028	0.0018	0.0011	0.0007	0.0004	0.0040	0.0035	0.104
Option 5	0.0065	0.0022	0.0013	0.0008	0.0227	0.0250	0.0018	0.0012	0.0007	0.0004	0.0003	0.0026	0.0023	0.068
Option 6	0.0043	0.0014	0.0009	0.0005	0.0150	0.0165	0.0012	0.0008	0.0005	0.0003	0.0002	0.0017	0.0015	0.045
Option 7	0.0030	0.0010	0.0006	0.0004	0.0103	0.0114	0.0008	0.0005	0.0003	0.0002	0.0001	0.0012	0.0010	0.031
	0.0963	0.0322	0.0194	0.0119			0.0270	0.0171	0.0104	0.0063	0.0040			
	0.1598				0.3343	0.3687	0.0648					0.0389	0.0335	
	1.0000													1.000

Figure 5.18 - Extract from the programme – Emphasis placed on *Quantity of Recyclate, Number of Waste Streams* and *Towards Zero Waste* Targets

		Legislative Compliance				No. of Streams	Quantity	Running Cost					Public Perception	Quality		Weightings for Alternatives
1		Best Waste Collection Method														
2		Recyclate, Reasidual, Food														
4		TZW	Fin. Pen	TEEP	Env Ben			Work Force	Fleet	APE	Contract	Rejects				
5	Option 1	0.0625	0.0372	0.0215	0.0128	0.0885	0.0563	0.0148	0.0093	0.0057	0.0035	0.0022	0.0226	0.0149		0.352
6	Option 2	0.0429	0.0255	0.0147	0.0087	0.0607	0.0386	0.0102	0.0064	0.0039	0.0024	0.0015	0.0155	0.0102		0.241
7	Option 3	0.0284	0.0169	0.0097	0.0058	0.0402	0.0256	0.0067	0.0042	0.0026	0.0016	0.0010	0.0103	0.0068		0.160
8	Option 4	0.0185	0.0110	0.0063	0.0038	0.0262	0.0167	0.0044	0.0028	0.0017	0.0010	0.0006	0.0067	0.0044		0.104
9	Option 5	0.0121	0.0072	0.0041	0.0025	0.0171	0.0109	0.0029	0.0018	0.0011	0.0007	0.0004	0.0044	0.0029		0.068
10	Option 6	0.0080	0.0047	0.0027	0.0016	0.0113	0.0072	0.0019	0.0012	0.0007	0.0004	0.0003	0.0029	0.0019		0.045
11	Option 7	0.0055	0.0033	0.0019	0.0011	0.0077	0.0049	0.0013	0.0008	0.0005	0.0003	0.0002	0.0020	0.0013		0.031
12		0.1777	0.1057	0.0610	0.0363			0.0421	0.0266	0.0162	0.0098	0.0062				
13		0.3806				0.2516	0.1602	[illegible]					0.0643	0.0425		
14		1.0000														1.000
15																

Figure 5.19 – Extract from the programme – The effect of *APE* on the scenario

5.4.13 Quantity of Recyclate & Public Perception

These two criteria are another example where their choice is complimentary. For the quantity of recyclate collected to be high, the public must participate in the proposed scheme. If the level of householder engagement is low, then no matter which solution alternative is used, the quantity of recyclate collected will be low. When the public perception of a scheme is high the users will be more inclined to use the service to the best of its abilities. Therefore, there is a positive correlation in the public perception and the quantity of recyclate collected.

A potential problem that could arise is that the quantity collected could be high, but the quality of this recyclate may suffer. The reason why the public may prefer one option over another is in its use. A commingled collection allows householders to dispose of waste in an easy fashion, using only a single receptacle. If the residual waste collection is not as regular as the recyclate collection, it may cause people to start disposing of non-recyclable waste in the recycling receptacle. If not policed properly, this waste can pass unnoticed on the collection round and the more this happens, the more a householder may carry on this practise. If the LA can deal with the separation of this non-recyclable waste, then this may be the preferred solution alternative.

On the other hand, if the authority cannot deal with this contamination of recyclate, there may be a Split Weighting characteristic with 3 criteria. In this scenario, it would be logical that *Quality of Recyclate* would become the third most important criterion. With this third criterion being on the upper side of the Split Weighting characteristic, it lessens the impact that *Quantity of Recyclate* and *Public Perception* have on the choice of alternative.

The effect is that the three criteria still have the same influence overall, on the selection of solution alternative. The nuance is that the reliance, for a particular alternative, is then spread among more than just two criteria. It can be seen in Figure 5.20 and 5.19, that the values that contributed to commingled collections, circled in green, have been lessened with the introduction of Quality as a third criterion in the Split characteristic. Inevitably, this would lead to a stronger case for KSS, however maybe not to the point where it is the preferred solution over commingled. This is because the two most important still have a strong influence in that direction. What can be noted is that should *Public Perception* diminish in the future, then it may not be as strong an argument for that choice.

The values for any of the criteria are split between the seven solution alternatives, to calculate their weightings. A higher weighting of the third strongest criterion indicates that it can have more effect on the choice of solution alternative. In Figure 5.20 a and b, the final weighting of the solution alternatives remains the same. How these values are attained differs. *Quantity of Recyclate* and *Public Perception* have weightings of 0.3847 and 0.3428 respectively in Figure 5.20a, an example of a 2-criteria Split Weighting Characteristic. When compared to Figure 5.20b, where a 3-criteria Split Weighting characteristic can be seen, these have a lower weighting yet remain the strongest two criteria, in this instance, with weightings of 0.3687 and 0.3131. *Quality of Recyclate* now has a weighting of 0.2520 indicating a higher importance than previously, of 0.1551 in Figure 5.20a. Even though the final weighting of the solution alternatives remain the same, the additive value from *Quality of Recyclate* is more in the 3-criteria Split Weighting characteristic. Option 1 is shown to be the best outcome overall however the ‘reliance’ on *Quantity of Recyclate* and *Public Perception* is less in Figure 5.20b than it is in Figure 5.20a.

5.4.14 Quality of Recyclate & Number of Streams collected

There is little reason to believe that there these two criteria would be found to be most important. The problem being that they are very conflictive. If the number of waste streams collected were to be maximised, it would most likely cause a drop in the quality of the recyclate received (Eunomia 2011).

There is also a split in the direction of which solution alternative would be most suitable. It is argued that KSS will provide a higher quality of recyclate to be collected (Eunomia 2011). Commingled collection allows for a higher number of streams to be collected. Therefore a hybrid system would likely appease this scenario. The inspection of streams such as paper and plastic to ensure no contamination and all remaining streams that wish to be collected, sorted at a later time, this could be a viable solution.

(a)

Best Waste Collection Method														
Recyclate, Reasidual, Food														Weightings for Alternatives
	Legislative Compliance				No. of Streams	Quantity	Running Cost					Public Perception	Quality	
	TZW	Fin. Pen	TEEP	Env Ben			Work Force	Fleet	APE	Contract	Rejects			
Option 1	0.0083	0.0049	0.0028	0.0017	0.0141	0.1353	0.0040	0.0025	0.0015	0.0009	0.0006	0.1205	0.0545	0.352
Option 2	0.0057	0.0034	0.0020	0.0012	0.0097	0.0928	0.0027	0.0017	0.0010	0.0006	0.0004	0.0827	0.0374	0.241
Option 3	0.0038	0.0022	0.0013	0.0008	0.0064	0.0614	0.0018	0.0011	0.0007	0.0004	0.0003	0.0547	0.0248	0.160
Option 4	0.0025	0.0015	0.0008	0.0005	0.0042	0.0400	0.0012	0.0007	0.0004	0.0003	0.0002	0.0357	0.0161	0.104
Option 5	0.0016	0.0009	0.0005	0.0003	0.0027	0.0261	0.0008	0.0005	0.0003	0.0002	0.0001	0.0232	0.0105	0.068
Option 6	0.0011	0.0006	0.0004	0.0002	0.0018	0.0173	0.0005	0.0003	0.0002	0.0001	0.0001	0.0154	0.0070	0.045
Option 7	0.0007	0.0004	0.0002	0.0001	0.0012	0.0118	0.0003	0.0002	0.0001	0.0001	0.0001	0.0106	0.0048	0.031
	0.0236	0.0140	0.0081	0.0048	0.0400	0.3847	0.0112	0.0071	0.0043	0.0026	0.0017	0.3428	0.1551	
	0.0504						0.0269							
	1.0000													1.000

(b)

Best Waste Collection Method														
Recyclate, Reasidual, Food														Weightings for Alternatives
	Legislative Compliance				No. of Streams	Quantity	Running Cost					Public Perception	Quality	
	TZW	Fin. Pen	TEEP	Env Ben			Work Force	Fleet	APE	Contract	Rejects			
Option 1	0.0085	0.0050	0.0029	0.0017	0.0144	0.1105	0.0039	0.0025	0.0015	0.0009	0.0006	0.1105	0.0886	0.352
Option 2	0.0058	0.0035	0.0020	0.0012	0.0099	0.0758	0.0027	0.0017	0.0010	0.0006	0.0004	0.0758	0.0608	0.241
Option 3	0.0039	0.0023	0.0013	0.0008	0.0066	0.0502	0.0018	0.0011	0.0007	0.0004	0.0003	0.0502	0.0402	0.160
Option 4	0.0025	0.0015	0.0009	0.0005	0.0043	0.0327	0.0012	0.0007	0.0004	0.0003	0.0002	0.0327	0.0262	0.104
Option 5	0.0016	0.0010	0.0006	0.0003	0.0028	0.0213	0.0008	0.0005	0.0003	0.0002	0.0001	0.0213	0.0171	0.068
Option 6	0.0011	0.0006	0.0004	0.0002	0.0018	0.0141	0.0005	0.0003	0.0002	0.0001	0.0001	0.0141	0.0113	0.045
Option 7	0.0007	0.0004	0.0003	0.0002	0.0013	0.0097	0.0003	0.0002	0.0001	0.0001	0.0001	0.0097	0.0078	0.031
	0.0241	0.0144	0.0083	0.0049	0.0410	0.3143	0.0111	0.0070	0.0043	0.0026	0.0016	0.3143	0.2520	
	0.0517						0.0266							
	1.0000													1.000

Figure 5.20 - Split Weighting Characteristic with (a) a 2 criteria as most important and (b) a 3-criteria Split Weighting characteristic with Quality of Recyclate in the top half of importance (right)

5.4.15 Quality of Recyclate & Public Perception

This scenario is similar to that of the *Quantity of Recyclate* collected and *Public Perception* scenario. If the public are inclusive of a scheme and want to participate, they are more likely to take ownership and therefore ensure that the quality is high. The householders will more likely understand what is permitted in to the receptacle(s) for recycling and give a higher quality and less contaminated recyclate.

This scenario is easier for small authorities, as there are less residents to appease. The best solution for this is the choice of a kerbside sort scheme. The quality is assumed to be better than commingled collections, so long as the public's perception from any given authority, is high. The KSS collection also requires more thought than a commingled collection thereby increasing the likelihood that the householder wants to participate. This is of course a subjective matter.

5.4.16 Public Perception & Number of Streams collected

This scenario is the least likely of all to happen when the results from Section 5.3 are considered. All the authorities place a very low importance rating on these two criteria. It is therefore a possibility in theory, but almost certain to not happen in practice. In theory, if there are more streams that can be collected, the public have to think less and may be more likely to participate. However, in this scenario, there is no thought to cost, targets, legislation or trying to increase the amount of recyclate collected by the authority. Whilst these two criteria are important in conjunction with any of the other four, on their own, there is no real driver to push the collection of recyclate further.

5.4.17 Summary

By setting these scenarios, the *Quality of Recyclate, Net Running Cost and Legislative Compliance* criteria have shown that they complement each other. To consider two of them as most important generally requires the third to understand the significance. This re-affirms the instinct decisions made by the stakeholders in Section 5.3 In turn, this gives confidence that those making the decisions in these authorities are focussing on more than just costs or reactive measures, which can cause the wrong long term decisions.

Through each scenario, similar problems arise for a LA in the collection of waste and recyclate. These problems are based on how to appease the remaining criteria when two, or sometimes three, are the main point of focus. It is true that if the decision making process is undertaken, there will be some that are of more importance to an authority. Whilst the remaining criteria have much less influence, it does not mean they can be ignored. All criteria have a contributory effect to the choice of recyclate collection (solution alternative). A key example is the *Public Perception* criterion. Whilst this generally is assumed to be low on the list of priorities of authorities, it must be taken into consideration at least. Without public input, any scheme is doomed to failure.

A lot of emphasis is placed on the costs involved with providing a waste collection service. This happens in any industry, however when budgets are constantly being squeezed and reduced, providing a better service than the previous year becomes harder. This is the demand and the main cause of concern, made by the Toward Zero Waste targets in Wales (WAG 2009). Authorities can change small things, for example collecting a new type of plastic, in the short term. In the long term, periodic radical overhaul is usually required. Sometimes, this is because plant needs replacing. It provides the perfect opportunity to research whether the same collection method can be used; or, because of changes in the industry, new technologies, new methods of reprocessing or any other reason, if a new collection method need to be implemented?

Of course, cost is not the only issue. By using the above scenarios, an authority can try to foresee the impact of considering various criteria in tandem. It is not concrete, as authorities have many variants to consider; but can provide the basis for the decision on a new type of collection in comparison to a current scheme.

There are small variations that occur depending on the emphasis of the decision being made. It is these variations that cause conjecture between the Government, and the direction they want to take, and Local Authorities. Although sixteen scenarios are laid out above, in theory, there are many more. When the consideration of residual waste is taken in to account as well, this creates sixty four scenarios. Including food collection, this number increases to one hundred and twenty eight scenarios. It is clear that this is a very complicated process. By concentrating on the implications of the choice of recyclate collection, the decision is manageable. Residual waste collection and food waste collection can be used as a confirmation exercise, as will be shown with the Case Study Authority.

It has been shown that focus on different criteria can mean different things to different types of authority; there can be variations when the most important criteria are the same. By organising the decision making process in terms of the criteria, the argument for the choice of solution alternative can be categorised. To check the validity of the scenarios, they are compared against the decision making process of the Case Study Authority. The following section is the result of their use of the programme and gives a suggested outcome. Although commingled recyclate collection and kerbside sort collection are covered in general in the scenarios, the Case Study Authority has more detailed versions of each type of collection, for comparison purposes.

5.5 Case Study Authority

Ceredigion is classed as a small authority by size and a rural authority by type. Previously it had been decided that a weekly commingled collection would be used, with a fortnightly residual waste collection. The reasoning for this is outlined in Section 3.4. The most pertinent questions are what have changed in the five years since then. Have the drivers and barriers changed? Are the alternatives considered then, the same as now? If not, why not, and how are the new solution alternatives different?

Further to these questions it is important to compare the two decision making processes, enabling an evaluation of how the decision making process has evolved over time. With the same final goal in the process undertaken by the Case Study Authority back in 2010 as now, this can easily be done.

5.5.1 Following the Decision Making Process Route Map

Alongside the research that was undertaken, the decision maker(s) in the Case Study Authority were asked to consider the route map outlined in Section 2.1. They were responsible for outlining the first four steps of the route map. The consultation process, which was defined in Section 4, aided the selection of the criteria, as per step five. Step six, the utilisation of a decision making tool, is defined in Section 2 along with justification for using the AHP methodology. The remainder of this section shows the application and appraisal of the decision made, following steps seven and eight of the decision making route map.

5.5.2 Defining the Problem – Step One

The decision to be made was defined as the following:

“Welsh Government insist that a Kerbside Sort approach to MSW collection is the best way forward. Is this the case for Ceredigion County Council? If not, what are the options available that are within legislative regulations and are within budgetary boundaries?

5.5.3 Requirements the solution must meet – Step Two

The chosen alternative must be accepted by the Welsh Government. The solution alternative must collect glass, paper, plastic and metal recyclate separately and the amount of biodegradable waste entering in to landfill must be within legislative targets.

5.5.4 Goals that should be accomplished – Step Three

The chosen solution alternative does not have to be the cheapest method, but the less expensive it is, the more favourable it will be. The solution alternative should be flexible to be able to cope with changes that may be needed over the course of its service life.

5.5.5 Selection of the Alternatives – Step Four

The options were chosen at a workshop involving senior officers and the Council’s portfolio member for waste. The selection of solution alternatives started with Business as Usual (BAU, the current method of collection) as the baseline. Next, the standard Welsh Government blueprint was added (Kerbside Sort with food collected on the same vehicle). The method of collection that the Case Study Authority thought would be the service they were hoping to offer (BAU plus glass collected weekly and

BAU plus glass collected fortnightly). A very basic option (recyclate collected fortnightly) was included to show the lowest possible price. Finally, a variation on the Welsh Government's Blueprint (Kerbside Sort with food collected on a separate vehicle) was included as another comparison.

5.5.6 Criteria Selection – Step Five

During the development of reviewing the decision making process in local authorities, the criteria were selected as *Legislative Compliance*, *Quantity of Recyclate* collected, *Quality of Recyclate* collected, *Number of Waste Streams* collected, *Net Running Costs* and *Public Perception*. Of these, the sub-criteria of *Net Running Costs* are *Fleet*, *Work Force, Advertising, Promotion and Enforcement* (*APE*), *Contract Costs* and *Gate Fees* and for Legislative Compliance the sub-criteria are *TZW Targets*, *TEEP Regulations*, *Financial Penalties* and *Environmental Benefits*.

5.5.7 Decision Making Tool – Step 6

The explanation for this the selection of methodology and development of that tool are outlined in Sections 2 and 4.

5.5.8 Application – Step 7

Before the tool is implemeneted and the decision making process can be undertaken, assumptions, agreements and disagreements must be documented to ensure clarity. These assumptions must be adhered to at all times to allow fairness in pairwise comparisons. Below are the assumptions and agreements made.

- *Residual Waste*

  The programme allows the user to consider different methods of recyclate collection alongside weekly, fortnightly, 3 weekly or monthly residual collections. For the Case Study Authority, only fortnightly residual waste is considered. There is a contract with the current MRF for this provision for another 5 years. The compensation required to break this contract is vastly more than projected savings and income from a change to another. Should the authority carry out the decision making process at the end of this contract, they would consider all recyclate collection types with the four frequencies for collection of residual waste.

- *Income*

  Leading on from the contract with the MRF, there is no income to the authority from the processed dry recyclate to consider. The MRF receives all recyclate and any income gained from selling processed recyclate goes directly to the MRF. So long as the quality is of a sufficient level, acceptable by the MRF, then financial impacts are unaffected. It was noted that if the council were to change their mind and set up transfer stations to process recyclate themselves, then quality becomes important for a better income.

- *Landfill allowance and penalties*

  Up to the present time, letters have been sent out to notify an authority for exceeding their landfill allowance. The same is true for not meeting targets, however, no financial penalties have been given. The process will be undertaken on the assumption that this will still be the case going forward.

- *Budget for the Local Authority*

  It is believed that in time, budgets will increase again. The public sector funding tends to see a lag when compared to private sector organisations in budget setting, due to tax revenue delay (Oakes 2014b). The money collected is not readily available to councils and forms the budgets a year or two later. The Case Study Authority are working on the assumption that now that the economy is recovering, the public sector will benefit from less budget cuts in the near future.

With these assumptions in place, information was input to the programme. The quantitative data used could not be included due to political sensitivity.

5.5.8.1 Entering information in to the programme

There is a 2-criteria Split Weighting characteristic, clearly defined in Figure 5.21. This is most similar to Large and Urban authorities in terms of characterisation. This is clearly not what was expected. A reason why the Case Study Authority results may not conform to the classification and characterisation results may be the time sensitive nature of the process. The results for characterisation and classification were attained about ten months before the final results. Over this time period priorities may have changed, however individual ideals and, more likely, contractual commitments confirm that there will never be conformity across all authorities in Wales; highlighted by the decision made by the Case Study Authority. There are many mitigating factors that affect a decision and the following studies the weightings assigned to all the criteria, sub-criteria and alternatives.

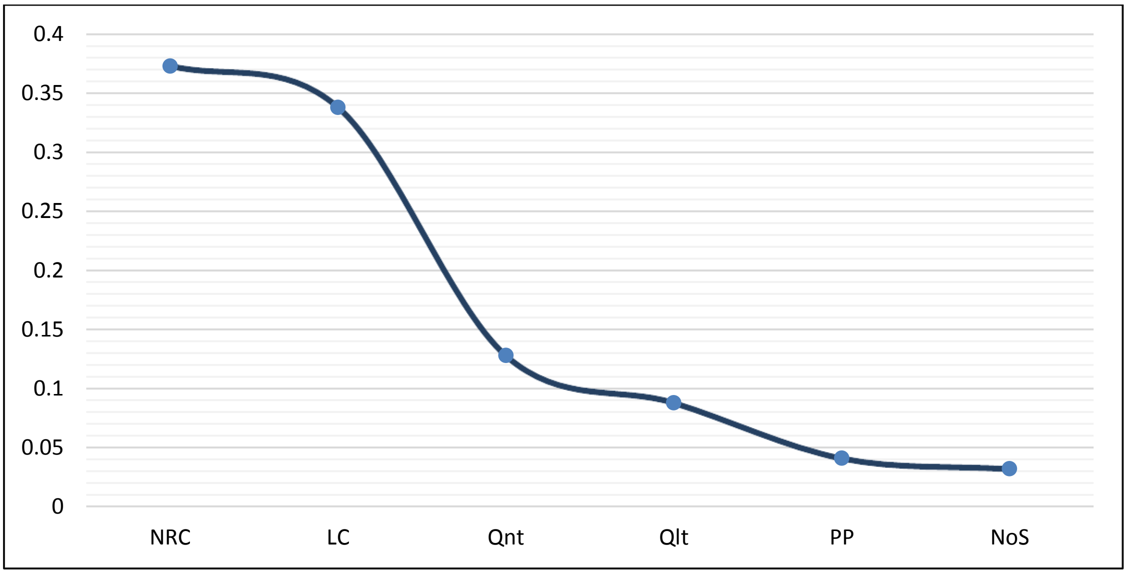


Figure 5.21 - Graphical Representation of the weightings for the six main criteria

With the data entered the results are shown in Figure 5.22, showing the two criteria that are most important to the Case Study Authority are *Net Running Cost* and *Legislative Compliance* with values of 0.373 and 0.338 respectively. This is not exactly in line with the expected outcome. A small rural authority would be expected to come out with *Net Running Cost* and *Quality of Recyclate* as the two most important criteria. For the Case Study Authority, the criterion *Quality of Recyclate* is fourth in importance behind *Quantity of Recyclate* collected as third in importance.

This is explained by the current contract that is in place with the MRF. *Quality of Recyclate* is not a priority, as only the minimum requirement requested by the MRF is acceptable to the authority. At present, a commingled collection satisfies the MRF's requirements. On the assumption that *at least* this standard will be achieved in the future, less importance is placed on quality. It has been noted that should, at the end of the contract, it be decided that looking to receive an income from the processing of recyclate be a priority for the LA, then the quality of recyclate collected would definitely become more important. However, it might not necessarily be more important than the quantity that can be attained. To maximise income, a large quantity of high quality recyclate would be required. The decision making process, at that time, would be required to make a judgement.

5.5.8.2 Net Running Costs

The pairwise comparisons of the sub-criteria are undertaken with the higher monetary value of one sub-criterion in comparison to another, leading to a higher importance weighting. When the solution alternatives are pairwise compared, with respect to the parent sub-criterion, the *lower* the cost of the alternative, the *higher* it's weighting. This difference is important. One of the goals for the council is looking to provide a service that is (preferably) as economical as possible. Whilst the sub-criteria that has the highest value overall is the most important, the alternative chosen should provide the service as inexpensively as possible.

Of the sub-criteria, the cost of the *Fleet* is vastly more important with a weighting of 0.609, seen in Figure 5.23, supplying a global weighting of 0.2273 in Figure 5.24, as it is the most expensive element. This is by far the largest contributing criterion (Top Heavy Weighting characteristic), with a weighting higher than those in the layer above, except *Legislative Compliance*. This emphasises the notion that authorities place so much importance on the cost of providing a service. The *Work Force*, *Contract/Tender Costs* and *Gate Fees* criteria have very similar weightings of 0.0447, 0.0356 and 0.513, and *APE* is near to insignificant.

The global weightings of the alternatives seen in Figure 5.24 are very small values, most of which are below 0.01 except in the *Fleet* column. Individually, they have a small input on the final weightings of the alternatives. If they are summed horizontally, they then begin to have more significance as a whole. Alternatives 2 and 6 stand out as the highest in weightings with 0.1292 and 0.0776 respectively. Alternative 1 is the next step down with a value of 0.050 followed by alternative 7 with a value of 0.0368. Alternatives 3, 4 and 5 have similar values of 0.0295, 0.0274 and 0.0229.

In Table 5.20, there is a comparison of the final weightings of the alternatives and the order of importance given by the net running costs. They nearly follow the same ordering of importance with clear exception of alternative 1, the BAU option. This is another point that emphasises the cost of providing the service, dominating the decision making process for this local authority.

Focussing on the alternatives, alternative 6 is the cheapest to run in terms of the work force cost and the contract costs. Alternatives 2, 5 and 7 send the least amount of waste to landfill and have the highest rate of recyclate capture. These alternatives have the highest and fairly similar weightings in the *Gate Fees* criterion. This underlines the idea that the cheapest service to run, alternative 5, is not necessarily the best choice as costs may be presented elsewhere.

	Best Waste Collection Method														Weightings for Alternatives
	Recyclate, Reasidual, Food														
	Legislative Compliance				No. of Streams	Quantity	Running Cost					Public Perception	Quality		
	TZW	Fin. Pen	TEEP	Env Ben			Work Force	Fleet	APE	Contract	Gate				
Option 1	0.0019	0.0019	0.0017	0.0054	0.0018	0.0182	0.0054	0.0270	0.0056	0.0100	0.0020	0.0021	0.0063		0.089
Option 2	0.0169	0.0169	0.0153	0.0054	0.0071	0.0182	0.0023	0.1068	0.0004	0.0009	0.0187	0.0023	0.0187		0.230
Option 3	0.0169	0.0169	0.0153	0.0054	0.0036	0.0182	0.0093	0.0093	0.0017	0.0043	0.0028	0.0158	0.0102		0.130
Option 4	0.0169	0.0169	0.0153	0.0054	0.0036	0.0182	0.0056	0.0093	0.0017	0.0029	0.0034	0.0158	0.0102		0.125
Option 5	0.0169	0.0169	0.0153	0.0054	0.0071	0.0182	0.0052	0.0049	0.0017	0.0065	0.0112	0.0014	0.0187		0.129
Option 6	0.0169	0.0169	0.0153	0.0054	0.0018	0.0182	0.0148	0.0477	0.0028	0.0100	0.0023	0.0011	0.0052		0.158
Option 7	0.0169	0.0169	0.0153	0.0054	0.0071	0.0182	0.0021	0.0223	0.0004	0.0009	0.0110	0.0023	0.0187		0.138
	0.1034	0.1034	0.0934	0.0381			0.0447	0.2273	0.0144	0.0356	0.0513				
	0.3383				0.0321	0.1276	0.3733					0.0407	0.0880		
	1.0000														1.000

Figure 5.22 - Excerpt from the programme of the final Case Study Authority Decision

Table 5.20 - Comparison of the order of importance for the alternatives, between *Net Running Cost* and overall

Alternative	NRC weighting		Alternative	Final Weighting
2	0.1292		2	0.230
6	0.0776		6	0.158
1	0.0500		7	0.138
7	0.0368		3	0.130
3	0.0295		5	0.129
4	0.0274		4	0.125
5	0.0229		1	0.089

Criteria	a	Work Force
	b	Fleet
	c	Advertising, Promotion & Enforcement
	d	Contract and/or Tender Costs
	e	Gate Fees

	a	b	c	d	e	Geomean	ω (weighting)
a	1	1/6	4	1	1	0.922	0.120
b	6	1	9	7	6	4.690	0.609
c	1/4	1/9	1	1/3	1/4	0.297	0.039
d	1	1/7	3	1	1/2	0.735	0.095
e	1	1/6	4	2	1	1.059	0.138

Figure 5.23 - Excerpt from the programme of the pairwise comparisons for *Net Running Cost* sub-criteria

	Running Cost				
	Work Force	Fleet	APE	Contract	Gate
Option 1	0.0054	0.0270	0.0056	0.0100	0.0020
Option 2	0.0023	0.1068	0.0004	0.0009	0.0187
Option 3	0.0093	0.0093	0.0017	0.0043	0.0028
Option 4	0.0056	0.0093	0.0017	0.0029	0.0034
Option 5	0.0052	0.0049	0.0017	0.0065	0.0112
Option 6	0.0148	0.0477	0.0028	0.0100	0.0023
Option 7	0.0021	0.0223	0.0004	0.0009	0.0110
	0.0447	0.2273	0.0144	0.0356	0.0513
	0.3733				

Figure 5.24 - Global Weightings of the solution alternatives for *Net Running Costs*, excerpt from the programme

In the decision making process, practically speaking, this is the decision made. However, what would the results be like if such an anomalous result is removed? With the weightings from the Fleet criterion zeroed, Figure 5.25 shows the weightings of the alternatives in this hypothetical situation. It shows how large an effect that one criterion, or ***sub***-criterion in this instance, can have on the outcome of the whole decision. Ceteris paribus, the final weighting of the alternatives are very close, with the exception of alternative 1.

The reason for alternative 1 being much lower is the assumption that the current method of MSW collection will not achieve the targets set out, going forward. Therefore, alternative 1's weightings under *TZW* and *Financial Penalties* are very low. Alternative 5 has the weighting 0.125 and alternative 6 has a weighting of 0.111. Of the alternatives that are not BAU, there is only a difference of 1% weighting between the highest and lowest. This is miniscule.

Figure 5.25 goes a long way to explaining why the cost of a service is nearly always the deciding factor. All the criteria are important and, when viewed in this way, are achieved to varying degrees, by the alternatives in this process. It is then the cost, and in particular the purchase/hire and running of vehicles that makes the final determining factor due to size of input on the decision in weighting.

It is very easy to accept that cost can be the determining factor. However, as has been stated many times in this chapter, ideals, motivations, criteria and targets are constantly changing in the decision making process for waste management. An iterative approach is required, wherever possible.

5.5.8.3 Legislative Compliance

The next highest criterion by weighting is *Legislative Compliance*. For the Case Study Authority, it was deemed that the alternatives all slightly excel what is required of them in regulations. The only anomaly to this is alternative 1, which will not achieve the targets set out and will not satisfy the necessity of collecting all four basic types of recyclate together. Therefore, in Figure 5.26, the weightings are much lower than the other six alternatives with 0.0019, 0.0019 and 0.0017 compared to 0.0169, 0.0169 and 0.0153 for each sub-criterion. *Environmental Benefit* is not compared as the Case Study Authority deemed it as a non-important criterion, thereby negating at that time.

	Best Waste Collection Method													Weightings for Alternatives
	Recyclate, Reasidual, Food													
	Legislative Compliance				No. of Streams	Quantity	Running Cost					Public Perception	Quality	
	TZW	Fin. Pen	TEEP	Env Ben			Work Force	Fleet	APE	Contract	Gate			
Option 1	0.0019	0.0019	0.0017	0.0054	0.0018	0.0182	0.0054	0.0000	0.0056	0.0100	0.0020	0.0021	0.0063	0.062
Option 2	0.0169	0.0169	0.0153	0.0054	0.0071	0.0182	0.0023	0.0000	0.0004	0.0009	0.0187	0.0023	0.0187	0.123
Option 3	0.0169	0.0169	0.0153	0.0054	0.0036	0.0182	0.0093	0.0000	0.0017	0.0043	0.0028	0.0158	0.0102	0.120
Option 4	0.0169	0.0169	0.0153	0.0054	0.0036	0.0182	0.0056	0.0000	0.0017	0.0029	0.0034	0.0158	0.0102	0.116
Option 5	0.0169	0.0169	0.0153	0.0054	0.0071	0.0182	0.0052	0.0000	0.0017	0.0065	0.0112	0.0014	0.0187	0.125
Option 6	0.0169	0.0169	0.0153	0.0054	0.0018	0.0182	0.0148	0.0000	0.0028	0.0100	0.0023	0.0011	0.0052	0.111
Option 7	0.0169	0.0169	0.0153	0.0054	0.0071	0.0182	0.0021	0.0000	0.0004	0.0009	0.0110	0.0023	0.0187	0.115
	0.1034	0.1034	0.0934	0.0381			0.0447	0.2273	0.0144	0.0356	0.0513			
	0.3383				0.0321	0.1276	0.3733					0.0407	0.0880	
	1.0000													0.773

Figure 5.25 - Excerpt from the programme of the Final Case Study Authority Decision, with the *Fleet* criterion negated

	Legislative Compliance			
	TZW	Fin. Pen	TEEP	Env Ben
Option 1	0.0019	0.0019	0.0017	0.0054
Option 2	0.0169	0.0169	0.0153	0.0054
Option 3	0.0169	0.0169	0.0153	0.0054
Option 4	0.0169	0.0169	0.0153	0.0054
Option 5	0.0169	0.0169	0.0153	0.0054
Option 6	0.0169	0.0169	0.0153	0.0054
Option 7	0.0169	0.0169	0.0153	0.0054
	0.1034	0.1034	0.0934	0.0381
	0.3383			

Figure 5.26 - Global weightings of *Legislative Compliance*, excerpt taken from the programme

5.5.8.4 Quantity of Recyclate

Quantity of Recyclate is the third most important criterion with a weighting of 0.1276. The Case Study Authority believed that the actual quantity of recyclate they can achieve is sufficient enough in all cases. Whether one alternative captured more recyclate than another was irrelevant to them due to the contractual agreement with the MRF. The analysis is therefore currently insignificant with respect to the global weightings gained by the alternatives and as such are, equal across all alternatives.

5.5.8.5 Quality of Recyclate

The quality that is gained from the solution alternatives is what led to the weightings shown for the *Quality of Recyclate* criterion. The pairwise comparisons were undertaken as judgements by the decision makers. Currently, it is very difficult to quantify and compare the quality of recyclate that is collected by kerbside collection schemes. It could be calculated by the percentage of rejects. However, different reprocessors will accept differing levels of contamination. Therein lays the difficulty in agreeing what quality means exactly.

Figure 5.27 shows alternatives 2 and 7 giving the highest quality in the opinion of the decision makers, both with 0.0187. As they are KSS options it follows the assumption they will offer a better quality, in general, of recyclate. Alternatives 3 and 4 are ‘hybrid’ methods of KSS and commingled collection, returning the next best quality and hence have a higher weighting than alternatives 1, 5 and 6 that are variations of commingled collections.

	Quality
Option 1	0.0063
Option 2	0.0187
Option 3	0.0102
Option 4	0.0102
Option 5	0.0187
Option 6	0.0052
Option 7	0.0187
	0.0880

Figure 5.27 – Global weightings of *Quality of Recyclate*, excerpt taken from the programme

The *Quality of Recyclate* criterion does not have a large impact in the decision. The contractual agreement with the MRF drives the reason for such a low weighting when compared to other criteria in the ***Drivers and Barriers*** layer. However, the authority did state that they must consider the quality of the recyclate they can achieve when that contract runs out. Otherwise, the global weightings across all the alternatives would have been identical.

5.5.8.6 Public Perception and Number of Waste Streams

The weightings attained by *Public Perception* and *Number of Waste Streams* follow the ideals of all the authorities in the classifications. With weightings of 0.0407 and 0.0321 respectively, they are not important to Local Authorities. Of interest in Figure 5.28 are alternatives 3 and 4 having significantly higher weightings, with respect to public perception than the remaining alternatives. These are the two options that are most similar to BAU, but including a glass collection. It is believed that the public are more likely to be accepting where little change to their use of the service is involved.

	Public Perception
Option 1	0.0021
Option 2	0.0023
Option 3	0.0158
Option 4	0.0158
Option 5	0.0014
Option 6	0.0011
Option 7	0.0023
	0.0407

Figure 5.28 - Weightings for *Public Perception*, excerpt taken from the programme

5.5.9 Checking the result with Food Collection

As a very basic method of checking the results from the decision, Figure 5.29 represents the preference of the decision makers of how to collect food waste. The higher the weighting of the option, the higher the preference in this instance. Using a compartment on a split body vehicle aligns with alternatives 1, 3, 4 and 5. A separate dedicated vehicle aligns with alternatives 6 and 7, whilst stillage vehicles are used for alternative 2.

The decision makers are in favour of split body vehicles in this case. As the food waste can be collected simultaneously with either residual or recyclable waste, a separate route is not required, thus lowering the cost of collection. The same is true for the use of stillage vehicles. In the same way, there is also less environmental impact using split body or pods on stillage vehicles as a single vehicle is used in a route.

The result here does not align with alternative 2 being the favoured alternative; neither does it agree that alternatives 6 and 7 second and third highest in weighting/preference. This does show that the opinion of decision makers cannot necessarily over-rule the effect of cost, for choosing a collection method. Therefore this proves that bias can be negated to a certain degree.

	Food Collection			Weighting
	Amt Collect	Cost	Env Ben	
Split Body	0.0664	0.4600	0.0324	0.559
Dedicated Vehicle	0.0664	0.1005	0.0162	0.183
Pod on Stillage	0.0664	0.1755	0.0162	0.258
	0.1993	0.7360	0.0647	
	1.0000			1.000

Figure 5.29 - Food collection preferences, excerpt from the programme

5.5.10 Compared to the appropriate scenario

Compared to the scenario created earlier in this chapter, the decision can be scrutinised. Firstly, progressive cutbacks in funding to LAs in Wales can be attributed to *Net Running Costs* being highest on the priorities. Also, the yearly targets that need to be achieved are principal on the Case Study Authorities goals. With alternative 2 being the favoured option, it is forecast to achieve both criteria.

The main problem that the authority would face is the standing contract with the MRF. The cost of breaking the current contract has not been accounted for in this decision because the exact cost has not been agreed upon and moreover, it may be possible to not break the contract completely. If residual waste is still sent to the MRF, recyclable waste can still be extracted, however the exact details are still unclear. As the Case Study Authority is currently exceeding targets, a major cause for concern is that a commingled collection may not be an acceptable form of collection in the future. This reflects the constantly changing drivers and barriers they face.

The Quantity of Recyclate criterion is third in importance. As stated in Section 5.4.2, again a commingled option would likely return a higher quantity of recyclate. It would have been expected that the addition of glass collection to the BAU, i.e. alternatives 3 and 4, would have gained a higher weighting. A similar collection service and fleet as the current one could be used and in terms of advertising and promotion, simple communications could be released as the householders would carry on almost as usual. Again, this outcome is blocked by the influence of the *Fleet* criterion. By looking at Figure 5.25, which negates the *Fleet* criterion, alternatives 2 and 3 have nearly the same weighting (0.123 and 0.120) whilst alternative 5 (a three stream collection) is slightly above both with a weighting of 0.125. As alternative 5 is a ‘hybrid’ collection between strict KSS and commingled collections, it would provisionally seem to satisfy all sides. Vehicle procurement and maintenance has such a large influence, it would all depend on the cost of breaking the current contract and the effect this would have on the decision.

In this scenario, it was predicted that a commingled collection would most likely be chosen. The large influence of the *Fleet* sub-criterion is the main reason why a commingled collection was not the most favoured option as it is estimated that the cost of vehicles in a KSS collection is much cheaper; otherwise a form of commingled collection would have had the highest weighting.

5.5.11 Summary

5.5.11.1 The Result

Alternative 2 is the preferred solution alternative, as evidenced by a final weighting of 0.230 in Figure 5.22. This is solely due to the vehicles that are to be used in this method of collection cost much less than the other alternatives. When considering the decision making process however, there are many complex areas that must be considered. The overriding criterion of the cost of the vehicles has skewed the decision in favour of this one alternative.

Figure 5.25 shows that with the fleet excluded, the pairwise comparisons and subsequent final weightings are very similar. However, this is for theoretical comparison methods only and cost is a component of the process. Therefore, it must be accepted that in this process, alternative 2, the Welsh Government Blueprint, is the preferable method of recyclate collection given these criteria, these solution alternatives and at the time the process was undertaken. Were any extra costs of changing the method of selection included, the process would need to be repeated and checked. This is particularly true of the cost of breaking the current contract with the MRF.

5.5.11.2 Accuracy

It must be noted that this was the decision taken at a particular point in time, for that particular authority. This result cannot be transposed to another authority or to another scenario. The process has to be repeated if the alternatives or the criteria selection change. To properly validate the scenarios and the criteria chosen, the tool would need to be tested with as many authorities in Wales as possible.

There are many reasons why this has not been done in this work. An authority must be in the process of evaluating or changing their collection method. Also, this process requires a lot of time. No decision maker will collect data and state preferences if they are not in the process of changing their method of collection, no matter how much you try to convince them! There was a reluctance by other authorities to undertake the process. They seemed keen at first, but were either not willing to give the time to undertake the analysis. This may partly be because they didn't want to take the chance that the result may contradict their reasoning for choosing a commingled collection. They also cannot necessarily state what their alternatives to be considered are either. To test the scenarios with the classifications would require many years to collect the information necessary.

By collecting more information and more results from authorities, the methodology can be better validated. With a higher number of results, the scenarios can be tested further and additional different decisions can be compared. Where results are the same, the differences between the reasoning behind their choices could be examined.

5.5.11.3 How the thought process changed

There was only one major area where the thought process changed for the Case Study Authority during this study. In 2011 when the consultation process with the Case Study Authority began, the concentration was completely on performance, no matter the cost. There were grants achievable that were financially attractive and it was thought best to exceed legislative targets. Now, in 2014/15, the decision makers question the need to spend, for example, an extra £1million to maybe achieve an extra 1% capture of recyclate? When the final results were attained, meeting statutory targets, not exceeding them, with the cheapest option was the mind-set.

5.5.11.4 Checking the Answers

Once the comparisons were made, then the preferred alternative was offered to the decision makers and any stakeholders to review and ensure that it meets all the requirements and achieves the goals to an agreeable point.

The decision to change the method of collection is a time sensitive process. The constraints are constantly changing and the motivations for achieving targets always change too. In the final meeting to obtain results, it was stated that in the previous decision the Sustainable Waste Management Grant (SWMG) was a driving factor. The amount of money on offer to the council to change their collection method was a great enough sum to adhere to its stipulations. At the present time, the decision makers believe that the changes asked for, to be eligible for the SWMG grant, are not suitable. Savings that equate to the extra income can easily be made elsewhere. Whilst the specifics of this were not clarified, it shows that the council's decision this time, is guided less by the grants on offer by the Welsh Government.

In spite of this, previously, options that did not align with the Welsh Government stance were initially considered (although immediately rejected before analysis). Compared to this process, all options had to be acceptable to Welsh Government, if not in complete concurrence with their blueprint, from the beginning of the decision making process.

A commonality of the two decisions is that they were triggered due to the need for a renewal of the fleet. Whilst contractual agreements are longer lasting, the fleet needs replacement approximately every four years. In light of this, it is understandable why the *Fleet* sub-criterion is so important. The cost involved is the trigger for making waste management decisions. The decision makers in the Case Study Authority said they would revisit the costings of the fleet, in light of this analysis and process.

Previously, only two criteria were considered, the cost of implementation and the environmental benefit they would bring. Both of these factors have been taken into account in the new decision making process. However, environmental benefit has now become quite insignificant in the view of the Case Study Authority. This is mainly because all the alternatives considered are conducive to a positive environmental outcome.

As stated in Section 3.5, there is still the possibility of falling into the trap of concentrating excessively on the costs of provision of the service. It is undeniable that cost is very important but it seems that in this case, the authority has allowed costs to primarily drive the decision.

5.5.11.5 Was it the Right Decision?

As this is a very subjective area, it is hard to say whether the outcome was the right decision. LAs would prefer a single type of bag collection that has all the material together and is sorted by a MRF. In cost terms, it would be the cheapest to implement and there would be very little promotional costs. For householders, it would be the easiest. For recyclate capture rates, it would 100%. However, the quality of recyclate would suffer due to high contamination rates and legislation ends this from being a choice of waste collection for LAs. Going forward, it is this author's belief that the quality of recyclate collected will become even more important.

It is the author's opinion that the cost assumptions that have been made are not a true and accurate reflection of what will happen if the alternatives were used. The relatively large saving that has been predicted by moving to a KSS collection is unlikely to be so large. If it is a true reflection of what could happen, the author believes that the Case Study Authority have fallen in to the trap of allowing cost to be the overriding criterion to make the decision. The global weighting of *Net Running Costs* is only just more than *Legislative Compliance*, but the one sub-criterion, *Fleet*, is *the* determining factor. One must also acknowledge that it is easier said than done in trying to reduce the dependency of the decision on cost alone for a LA.

The author also believes that although a high priority is placed on *Legislative Compliance*, it does not contribute to the choice of alternative. The sub-criteria are all, more or less, 'switched off' in the decision, thereby giving no contributory effect to the selection of alternative. The message this puts across is that achieving legislative targets and adhering to constraints is important but does not actually contribute to the overall decision. In reality, this is not the case. The choice of alternative can directly influence the percentage of waste that is recycled and subsequently collected. The difficulty is that without physically implementing the collection type, only estimations for the recycling rates can be made. If the recycling rates of the KSS collections can be achieved, then the pairwise comparisons of the alternatives, in relation to the sub-criteria of *Fleet*, are accurate. If they cannot, then the pairwise comparisons are wrong and would be revisited in future analysis.

Going forward, there is an increased focus on the quality of recyclate that is collected. In this decision, the Case Study Authority have placed a very low importance on the quality of the recyclate. The MRF contract will allow a certain amount of contamination. Therefore, in the opinion of the author, the *Quality of Recyclate* criterion should have a higher weighting overall and be on a par with the *Quantity of Recyclate* criterion. It is the author's opinion that this will be the case in the future.

If it is assumed that the assumptions and information is correct and an accurate forecast of implementation of all the alternatives, then the argument for the Welsh Government is strengthened. The perceived cost, environmental benefit and legislative target achievement agree that the KSS collection, Alternative 2, is the most appropriate choice for the Case Study Authority. It is contradictory to the anecdotal opinions voiced by the decision makers. The recommendation put forward by the author is to revisit the assumptions made and if they are agreed to be correct, the decision should be to implement a Kerbside Sort collection.

As it agrees with WG, it will be difficult to say that commingled should still be used going forward. WG will be applying more pressure to LAs to conform to one united method of collection across Wales. With an increasing amount of legislation, this author believes that it will become very difficult for LAs to implement commingled collections in the near future. The WG will likely use the restructuring of authority boundaries to help in this manner. It would seem that over time, householders end up accepting whichever collection method is used in their authority. The recycling rates have continuously gone up over an extended period of time. It is the author's view that there is nothing to suggest that a Wales-wide collection method would adversely affect their participation.

5.6 Restructuring of Local Authorities

In January 2014, it was found by a Commission (Williams 2014), that there should be a restructuring of Local Authorities in Wales. This would see the authorities combined in different ways to provide their public services, with one example being:

- Anglesey & Gwynedd
- Conwy & Denbighshire
- Flintshire & Wrexham
- Ceredigion, Carmarthenshire & Pembrokeshire
- Powys
- Monmouthshire & Newport
- Blaenau Gwent, Torfaen & Caerphilly
- Merthyr Tydful & Rhondda Cynon Taf
- Cardiff & Vale of Glamorgan
- Neath Port Talbot & Bridgend
- Swansea

If these new Local Authorities are created by 2018, as the commission suggests, what does this mean in terms of waste management?

If there is an imbalance in the landfill tax, this can create a migration of waste across borders so that the authorities can achieve targets and avoid penalties. Wales will be able to set their own taxes, including that of Landfill Tax to mitigate this dilemma (Hutt 2015). What effect would this have on the provision of waste collection? When coupled with the drive for the Welsh Government Blueprint, is this the opportunity for all of Wales to have the same method of waste collection? It certainly looks that way.

With the amalgamation of authorities, there is uncertainty whether waste management could it be run from two or three separate entities and remain ‘business as usual’. Or would it have to be centralised in the new authorities? Centralisation would most likely occur over an extended period of time if the LA boundaries were to be reassigned. This would allow for budgets to be renegotiated, employees to be reassigned and eventually a decision making process to be followed for the choice of waste management service.

This would lead to further cost implications such as how to run a fleet over a larger area? How would the facilities be managed? If there is a MRF available in one ‘old’ authority, could process all the waste collected from the new larger one? The authorities that merge may be running two different types of scheme. All of these factors would factor in to a new decision making process that could potentially have many more criteria than outlined previously. A judgement would have to be made with regards the quality of recyclate collected over a much larger area. Finally, there could be disagreements regarding legislative compliance. Whilst some authorities are over-achieving, if they are paired with one or two authorities that are under-achieving targets set out in regulations, there may be some discord. All of these would have to be resolved before the decision making process could be undertaken.

At the present time, just over half of the councils in Wales are using a commingled collection. If a restructure presented the opportunity for the Welsh Government to force the use of Kerbside sorting, what would the consequences be? Firstly, the MRFs would all become ‘dirty’ MRFs, sorting only residual waste from Wales. The throughput would fall drastically and they would most likely start bringing commingled recyclate from England. Otherwise, their revenues would fall drastically, due to decreased demand from the Welsh Authorities, and possibly lead to a loss of jobs. If this series of events were to come to fruition, then there could be public criticism in not supporting local jobs.

However, the counter argument is that there would be more scope for jobs as operatives of the KSS collection. Those that may lose jobs at MRFs could be retrained, if they so wished, for working in collection to mitigate this loss. This is all dependent on the participation of householders.

If householders who were using commingled collections accepted and participated in the new collection scheme, then the quality and quantity of recyclate could increase. This in turn would lead to the demand for more collection operatives. The opposite could also be true. The householders may prefer a commingled collection as it generally involves less work for them. If it were forced upon them to change and participation rates dropped, less operatives would be needed.

It is impossible to predict how the situation would evolve. One thing is for certain at the current time. The Welsh Government believe that Kerbside Sort collection is the future for Wales. This can be analysed using the three most expected scenarios outlined in Section 5; starting with the most likely, *Net Running Cost* and *Legislative Compliance* Split Weighting characteristic.

For the new authorities, it may be hard to achieve legislative compliance at first. This is dependent on their recycling rates and the collection systems that the two or three ‘old’ authorities have. If one of these authorities are below legislative recycling targets, it will bring the average of the ‘new’ authority down. It is likely that the first aim for ‘new’ authorities will be to ensure their rates are achieving the requirements. The Welsh Government (WG) will, in all probability, provide a grace period to allow for the change. The WG will possibly use the merging of authorities as an opportunity to use legislation to get new authorities to adopt KSS collection as well. Again, to appease and incentivise authorities, they may offer many grants, similar to the Sustainable Waste Management Grant, to aid in transition.

When considering *Net Running Cost* and *Quality of Recyclate*, the quality of the recyclate may suffer at first. When large scales of operation are first introduced, there is a potential for confusion for householders. If the residents have become used to a certain method of collection, transition to a new one may cause a dip in quality. Nevertheless, this should not be any more the case than the introduction of a new scheme in current authority boundaries. If a KSS collection is used, then a drop in the quality will cause a drop in the income attained from reprocessed recyclate, thus negatively affecting the *Net Running Cost* criterion weighting.

Lastly, the *Legislative Compliance* & *Quality of Recyclate* scenario can be considered. If these two criteria were considered most important, it strengthens the argument for selecting a KSS collection scheme. If legislation were introduced that quantifies the level of quality in recyclate, KSS would lend itself as there would be lower levels of contamination. If this came to fruition it would raise the question, in the decision tree, should the *Quality of Recyclate* criterion become a sub-criterion under *Legislative Compliance*?

Whatever the outcome of the restructuring of local authorities in Wales, there will be a period of time where it is ‘Business As Usual’ with regards to the collection of household waste. The ‘new’ authorities will take a year or two to amalgamate their collection methods and decide on the best method for them. At that time, analysis using the tool outlined in this thesis, along with the setting of scenarios for comparison will give a comprehensive decision making method that can be repeated in the future.

6. Conclusions and Recommendations

6.1 Conclusions

Constant changes in legislation and the repatriation of powers to a more devolved Wales have led to significant changes across the economy. Waste management is involved in this continuous change. The Welsh Government have outlined that all authorities should carry out the same method of kerbside collection, Kerbside Sort, to allow for greater efficiencies. However, only seven out of twenty-two authorities have decided that this method is most appropriate for them. With a large number of variables to consider, the decision is complex.

This thesis has examined decision making process in the context of waste management and particularly recyclate collection where the Analytic Hierarchy Process is used as the methodology. As a method, its effectiveness in implementation and understanding is a major strength yet it has been proven as a robust decision making method. AHP allowed the criteria to be compared in a way that the user could understand to give meaningful results by the Case Study Authority.

6.1.1 Conclusions of Scenarios

The criteria were selected through a lengthy iterative process to understand what areas of importance are taken in to account by Local Authorities. By starting with as many drivers and barriers to waste management as possible, the decision makers could narrow down on the areas they considered important. Through repeated meetings with various authorities and decision makers to test the programme, the final six criteria that were agreed upon.

The scenarios created represent an expressive way to understand the decision making process. By classifying the authorities by size and by type, a more generic picture is revealed in how waste management can be structured in similar authorities. More comparisons of these scenarios to Case Study Authorities is required to ascertain how accurate they are.

It was clear that no 'one size fits all' approach will work well. The individual characteristics of each authority mean that their main area of focus, other than cost, will never be the same. The decision making process needs to be carried out when there are changes in circumstance and an alteration in the method of collection is required. It was expected that they would find that criteria *Net Running Costs* and *Quality of recyclate* as the most important. In fact they found *Net Running Costs* and *Legislative Compliance* as most important. Their use of a MRF meant that quality of the recyclate they collect is of less importance to them. This proves that even when narrowed down by type, authorities will not always be able to conform to expectations, even if they would like to.

6.1.2 Case Study Authority

For the Case Study Authority it was found that the Welsh Government's favoured approach, a Kerbside Sort collection, is most favourable. The main driving factor is the cost of vehicles being so much lower. Aside from this, the weighting and preference for all the solution alternatives were very similar. With compliance of legislation being high on their priorities, it would be wise to start using a method that is flexible enough to deal with unknown changes in the future.

There was a change in mind-set from the beginning to the end. This process is time sensitive, as can be seen in the case study. Due to current contracts, there is no focus on quality. If they look to receive an income in the future, then quality and quantity of the recyclate they collect will become more important. No two decisions with any considerable time between them will ever be the same. Equally, no two councils will be the same. However, they will generally conform to their type.

6.1.3 Have the Aims and objectives been met?

- ***To understand the decision making process and explore the complexity of the decision making process in waste management it can be understood.***

  The literature review provides a comprehensive review of decision making as a whole and how decision making has been applied to waste management. By understanding these two points, a novel approach to researching the decision making process for the collection of kerbside collected waste could be identified. The Analytic Hierarchy Process was developed successfully through the creation of the 'decision tree' and it's refinement to accurately map the decision making process.

- ***To clarify the Drivers and Barriers and outline the main criteria for Local Authorities.***

  The consultation with Local Authorities, waste operators and the Welsh Government led to the refinement of the decision tree to its final iteration. The time sensitive nature of decision making in waste management means that this constantly had to be revised, to reflect the current conditions the authorities are working under. In testing the tool, it was clear that LAs sometimes contradicted themselves. An example is that *Legislative Compliance* was considered important to the Case Study Authority, however the subcriteria that feed in to it were not and therefore ignored. This should clearly not be the case.

- ***Develop a tool that implements a decision making methodology, to aid the multifaceted process, given the legislative, economic, environmental and social pressures, in a kerbside collection.***

  Using AHP as the underpinning methodology to a new tool has proven successful. The decision outcome was not completely accepted by the case study authority as a true reflection of their choices. It highlighted discrepancies in the cost assumptions that have been made, which will be reviewed by them. How the outcome can easily be skewed by cost, was evidenced by the *Fleet* sub-criterion and the comparison when it was negated. It is this comparison that was accepted as being a closer reflection of the opinions of the decision makers in the Case Study Authority. The main limitation is that the tool needs to be expanded to include food collection as part of the main consideration.

- ***To create scenarios for classification of authorities and comparison against a case study authority, to judge whether the decision made was correct.***

  The scenarios create a clear understanding of the potential shifts in focus in relation to criteria. They create comparable areas for authorities that are ultimately unique. The results of the Case Study Authority somewhat agreed with the scenarios but needs more testing with a wider range of authorities to improve accuracy. Compared to the previous decision making method the one proposed is more complex and reflected the current decision process. This method can be accurately repeated in the future to map changes in criteria and choices to make.

6.1.4 Other nuances?

Ironically, there was a lot of indecision in the selection of the criteria. An example of this is the consideration of the *Quality of Recyclate* criterion. As described in the iterative process, it was included, excluded and then included again in the decision tree. For the Case Study Authority, they would not consider quality of recyclate at the time of analysis. However, due to external pressures it was re-inserted. It was understood that the time sensitivity would cause regular changes to the decision making process, but one would not expect them to be over such a short period of time. This creates the validity of a decision to be short lived causing difficulty in committing to a service that will be provided over approximately four years.

This thesis has made a contribution to the field as looking in to waste management in this distinct way has not been done before; applying a particular decision making process for the collection of recyclate in this way, directly to an authority, rather than trying to make a generic one that fits all. Many decision making tools in the industry focus solely on cost and maybe include environmental benefits. This is not necessarily a true reflection of the decision making process. The actual decisions that are undertaken also consider other areas such as those outlined, especially those of the ***Drivers and Barriers*** outlined in this study.

6.2 Future Work

It is recommended that future research in this area considers the following:

- To select the criteria, it would be preferable to have a wider audience for the selection of criteria all authorities, preferably all authorities in Wales, having an input. In this way, if it were to be tested with all of them, the tool and methodology would be relevant to all. Also, having a longer timescale would be necessary as the decision making process constantly changes with time;

- More comprehensive modelling and inclusion of food waste. This could be done through the inclusion of food in the decision tree or creating a second, parallel, decision making tree specifically for food. The basic food checking method could be developed for this and the results would *have* to match for a correct decision;

- The use of Life Cycle Analysis should an authority wish to prove that another method of collection, other than Kerbside Sort, is more efficient. If an authority has a severe aversion to the use of Kerbside Sort collection a Life Cycle Analysis should be included. This could either be as an add on and considered separately, or included as a module/criterion in the ***Drivers & Barriers*** layer;

- Carry out analysis with more Case Study Authorities to validate the scenarios and have an opportunity to gather results for weekly, fortnightly, three weekly and monthly collections of residual waste. The accuracy of the outcome is not validated due to this. By applying more case studies, the scenarios can be validated and adjusted to more definitively reflect situations in Wales

7. References

2008/98/EC 2008. *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives*. EU.

75/442/EEC 1975. *COUNCIL DIRECTIVE of 15 July 1975 on waste*. EEC.

Abbe, O.E., Grimes, S.M. and Fowler, G.D. 2011. Decision support for the management of oil well drill cuttings. *Proceedings of Institution of Civil Engineers: Waste and Resource Management* 164(4), pp. 213–220.

Alonso, J.A. and Lamata, M.T. 2006. Consistency in the analytic hierarchy process: A new approach. *International Journal of Uncertainty, Fuzziness and Knowlege-Based Systems* 14(4), pp. 445–459.

Anojkumar, L., Ilangkumaran, M. and Sasirekha, V. 2014. Comparative analysis of MCDM methods for pipe material selection in sugar industry. *Expert Systems with Applications* 41(6), pp. 2964–2980.

Anon 2014. Private Conversation - Rhondda Cynon Taf.

API 1991. Developing Area specific Waste Management Plans for Exploration and Production Operations.

Astrup, T., Riber, C. and Pedersen, A.J. 2011. Incinerator performance: effects of changes in waste input and furnace operation on air emissions and residues. *Waste Management & Research* 29(10 Suppl), pp. S57–S68.

Baker, D., Bridges, D., Hunter, R., Johnson, G., Krupa, J., Murphy, J. and Sorenson, K. 2001. *Guidebook to Decision-Making Methods*. Department of Energy, USA.

Bani, M.S., Rashid, Z.A., Hamid, K.H.K., Harbawi, M.E., Alias, A.B. and Aris, M.J. 2009. The development of decision support system for waste management; a review. *World Academy of Science, Engineering and Technology* 37, pp. 161–168.

Barron, F.H. and Barrett, B.E. 1996. The efficacy of SMARTER - Simple Multi-Attribute Rating Technique Extended to Ranking. *Acta Psychologica* 93(1-3), pp. 23–26.

Baumann, H. and Tillman, A.-M. 2012. The Hitch Hiker's Guide to LCA. In: 1:7 ed. Lund, Sweden: Studentlitteratur, pp. 19–42.

Beach, L.R. 1996. *Decision making in the workplace*. Mahwah, NJ: Lawrence Erlbaum Associates.

Behzadian, M., Kazemzadeh, R.B., Albadvi, A. and Aghdasi, M. 2010. PROMETHEE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research* 200(1), pp. 198–215.

Bhatnagar, A., Kaczala, F., Hogland, W., Marques, M., Paraskeva, C.A., Papadakis, V.G. and Sillanpää, M. 2014. Valorization of solid waste products from olive oil industry as potential adsorbents for water pollution control--a review. *Environmental science and pollution research international* 21(1), pp. 268–98.

Bolden, J., Abu-Lebdeh, T. and Fini, E. 2013. Utilization of Recycled and Waste Materials in Various Construction Applications. *American Journal of Environmental*

Sciences 9(1), pp. 14–24.

Bouyssou, D. 2001. Outranking Methods. *Encyclopedia of Optimization* 4, pp. 249–255.

Brans, J.-P. and Mareschal, B. 2005. PROMETHEE Methods. In: Figueira, J., Greco, S., and Ehrgott, M. eds. *Multiple Criteria Decision Analysis: State of the Art Surveys*. Springer New York, pp. 163–195.

Brans, J.P., Mareschal, B. and Vincke, P. 1984. PROMETHEE: A New Family of Outranking Methods in Multicriteria Analysis. In: *Operational Research*. Washington, DC, USA: North-Holland, pp. 477–490.

Brans, J.-P. and Vincke, P. 1985. A Preference Ranking Organisation Method: (The PROMETHEE Method for Multiple Criteria Decision-Making). *Management Science1* 31(6), pp. 647–656.

Buchanan, J., Sheppard, P. and Vanderpoorten, D. 1998. Ranking projects using the ELECTRE method. In: *Operational Research Society of New Zealand, Proceedings of the 33rd Annual Conference*. pp. 42–51.

Cabinet Office 2006. *Government of Wales Act 2006*.

Cabinet Office 1998. *Scotland Act 1998*.

Callan, T., Leventi, C., Horacio, L., Matsaganis, M., Paulus, A. and Sutherland, H. 2011. The Distributional Effects of Austerity Measures: A Comparison of Six EU Countries. *EUROMOD* Working Pa(August), pp. 1–36.

de castella, T. 2011. Tipping point: what happens when our landfills are full? *The Telegraph*.

Cellini, S.R. and Kee, J.E. 2010. *Cost-effectiveness and Cost-Benefit Analysis. In: Handbook of Practical Program Evaluation*. 3rd ed. Wholey, J. S., Hatry, H. P., and Newcomer, K. E. eds. Wiley.

Cerdegion CC 2010. *Ceredigion Improvement Plan 09/10 - Promote sustainable development and resource management*.

Ceredigion CC 2010. *Future Reuse and Recycling Collections*.

Chanvarasuth, P. and Boongasame, L. 2014. How to Make a Decision: The Analytic Hierarchy Process. *Asia Pacific Journal of Tourism Research*, pp. 1–14.

Chen, H.W. and Chang, N.-B. 2000. Prediction analysis of solid waste generation based on grey fuzzy dynamic modeling. *Resources, Conservation and Recycling* 29(1-2), pp. 1–18.

Coello Coello, C.A., Lamont, G.B. and Van Veldhuizen, D.A. 2002. *Evolutionary algorithms for solving multi-objective problems*. 2nd ed. New York: Kluwer Academic.

Cole, E.J. and Fieselman, L. 2013. A community-based social marketing campaign at Pacific University Oregon. *International Journal of Sustainability in Higher Education* 14(2), pp. 176–195.

Contreras, F., Hanaki, K., Aramaki, T. and Connors, S. 2008. Application of analytical hierarchy process to analyze stakeholders preferences for municipal solid waste management plans, Boston, USA. *Resources, Conservation and Recycling*

52(7), pp. 979–991.

Corrente, S., Greco, S. and SŁowiński, R. 2013. Multiple Criteria Hierarchy Process with ELECTRE and PROMETHEE. *Omega (United Kingdom)* 41(5), pp. 820–846.

Costi, P., Minciardi, R., Robba, M., Rovatti, M. and Sacile, R. 2004. An environmentally sustainable decision model for urban solid waste management. *Waste management (New York, N.Y.)* 24(3), pp. 277–95.

Council of the European Union 1999. *Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste (The Landfill Directive)*. EU.

Curry, R., Powell, J., Gribble, N. and Waite, S. 2011. A streamlined life-cycle assessment and decision tool for used tyres recycling. *Proceedings of Institution of Civil Engineers: Waste and Resource Management* 164(4), pp. 227–237.

Dalemo, M., Sonesson, U., Björklund, A., Mingarini, K., Frostell, B., Jönsson, H., Nybrant, T., Sundqvist, J.-O. and Thyselius, L. 1997. ORWARE – A simulation model for organic waste handling systems. Part 1: Model description. *Resources, Conservation and Recycling* 21(1), pp. 17–37.

Date, W. 2014a. Defra lays MRF Code regulations [Online] Available at: http://www.letsrecycle.com/news/latest-news/defra-lays-mrf-code-regulations/ [Accessed: 2 March 2014].

Date, W. 2014b. Gwynedd approves three-weekly collection switch [Online] Available at: http://www.letsrecycle.com/news/latest-news/gwynedd-approves-three-weekly-collection-switch/ [Accessed: 15 October 2014].

David, R., Ngulube, P. and Dube, A. 2013. A cost-benefit analysis of document management strategies used at a financial institution in Zimbabwe: A case study. *SA Journal of Information Management* 15(2), p. 10 pages.

DEFRA 2011a. *Anaerobic digestion strategy and action plan*. London, UK.

DEFRA 2009. *Landfill Directive Briefing paper*. UK.

DEFRA 2011b. *The Landfill (Maximum Landfill Amount) Regulations 2011*.

DEFRA 1996. *The Landfill Tax Regulations 1996*. UK.

DEFRA 2012. *The Waste (England and Wales) (Amendment) Regulations 2012*.

DEFRA 2011c. *Waste (England and Wales) Regulations 2011*. UK.

Edwards, W. and Barron, F.H. 1994. SMARTS and SMARTER: Improved Simple Methods for Multiattribute Utility Measurement. *Organizational Behavior and Human Decision Processes* 60(3), pp. 306–325.

EEA 2013. *Managing Municipal Solid Waste - a review of achievements in 32 European Countries*. Copenhagen, Denmark.

Emery, A., Griffiths, A.J., Williams, K.P. and Woollam, T.C. 2004. Do you really participate in kerbside recycling? In: *19th International Conference on Solid Waste Technology and Management*.

Eriksson, O., Frostell, B., Björklund, A., Assefa, G., Sundqvist, J.-O., Granath, J., Carlsson, M., Baky, A. and Thyselius, L. 2002. ORWARE—a simulation tool for waste management. *Resources, Conservation and Recycling* 36(4), pp. 287–307.

Eunomia 2011. Kerbside Collections Options: Wales.

Eunomia and WRAP 2015. *Gate Fees Report 2015*. Bristol, UK.

Eurostat 2014. Eurostat - Tables, Graphs and Maps Interface (TGM) graph [Online] Available at: http://epp.eurostat.ec.europa.eu/tgm/graph.do?tab=graph&plugin=1&pcode=ten00106&language=en&toolbox=data [Accessed: 12 June 2014].

Eurostat 2013a. Eurostat statistics [Online] Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/main_tables [Accessed: 9 June 2014].

Eurostat 2013b. Eurostat statistics - About Eurostat [Online] Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/about_eurostat/introduction [Accessed: 22 July 2014].

Eurostat 2013c. Generation of waste by economic activity [Online] Available at: http://epp.eurostat.ec.europa.eu/tgm/refreshTableAction.do;jsessionid=9ea7d07e30e826c00e1854ae4cc5b3d387be24ea7027.e34OaN8Pc3mMc40Lc3aMaNyTbhiKe0?tab=table&plugin=1&pcode=ten00106&language=en [Accessed: 10 June 2014].

Eurostat 2012. Metadata in Euro SDMX Metadata Structure (ESMS) [Online] Available at: http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/EN/env_wasmun_esms.htm [Accessed: 5 May 2014].

Evangelisti, S., Tagliaferri, C., Clift, R., Lettieri, P., Taylor, R. and Chapman, C. 2015. Life cycle assessment of conventional and two-stage advanced energy-from-waste technologies for municipal solid waste treatment. *Journal of Cleaner Production* 100, pp. 212–223.

De Feo, G. and De Gisi, S. 2010. Public opinion and awareness towards MSW and separate collection programmes: a sociological procedure for selecting areas and citizens with a low level of knowledge. *Waste management (New York, N.Y.)* 30(6), pp. 958–76.

Figueira, J., Greco, S. and Ehrgott, M. 2005. *Multiple Criteria Decision Analysis: State of the Art Surveys*. New York, NY, USA: Springer New York.

Figueira, J., Mousseau, V. and Roy, B. 2005. ELECTRE Methods. In: Figueira, J., Greco, S., and Ehrgott, M. eds. *Multiple Criteria Decision Analysis: State of the Art Surveys*. Springer New York, pp. 133–153.

Fontenelle, M.R. and Bastos, L.E.G. 2014. The multicriteria approach in the architecture conception: Defining windows for an office building in Rio de Janeiro. *Building and Environment* 74, pp. 96–105.

Fülöp, J. 2005. Introduction to Decision Making Methods. *Laboratory of Operations Research and Decision Systems: Computer and Automation Institute, Hungarian Academy of Sciences*.

Fylde Council 2014. Rubbish Removal for Bulky and Large Items (Special Collections) • Fylde Borough Council [Online] Available at: http://www.fylde.gov.uk/resident/recycling-refuse/rubbish-removal-bulky-large-items-special-collecti/ [Accessed: 17 June 2014].

Garbett, J. 2010. A Comparison of Waste Management Strategies and Recycling Rates. MEng Dissertation, Cardiff School of Engineering.

Government 2002. *The Landfill (England and Wales) Regulations 2002*. UK.

Green, M. and Weatherhead, E.K. 2014. Coping with climate change uncertainty for adaptation planning: An improved criterion for decision making under uncertainty using UKCP09. *Climate Risk Management* 1, pp. 63–75.

Greenhalf, M. 2012. Waste Contract Data Manager, Private Consultation - London Borough of Southwark.

Gross, T., Lafortune, J. and Low, C. 2014. What Happens the Morning After? The Costs and Benefits of Expanding Access to Emergency Contraception. *Journal of Policy Analysis and Management* 33(1), pp. 70–93.

Guitouni, A. and Martel, J.-M. 1998. Tentative guidelines to help choosing an appropriate MCDA method. *European Journal of Operational Research* 109(2), pp. 501–521.

Gutiérrez, M.C., Martín, M.A., Serrano, A. and Chica, A.F. 2015. Monitoring of pile composting process of OFMSW at full scale and evaluation of odour emission impact. *Journal of environmental management* 151, pp. 531–9.

Hahn, W.J., Seaman, S.L. and Bikel, R. 2012. Making decisions with multiple attributes: A case in sustainability planning: How managers can use decision analysis techniques to include both quantitative and qualitative factors in their decision-making. *Graziadio Business Report* 15(2).

Hall, C.C., Ariss, L. and Todorov, A. 2007. The illusion of knowledge: When more information reduces accuracy and increases confidence. *Organizational Behavior and Human Decision Processes* 103(2), pp. 277–290.

Harrabin, R. 2008. Living in a world without waste [Online] Available at: http://news.bbc.co.uk/1/hi/sci/tech/7502071.stm [Accessed: 16 May 2015].

Harris, R. 1980. What Is Decision Making? [Online] Available at: http://www.virtualsalt.com/crebook5.htm [Accessed: 15 November 2011].

HM Treasury 2014. *Budget 2014*. London: Crown.

Hokkanen, J. and Salminen, P. 1997. Choosing a solid waste management system using multicriteria decision analysis. *European Journal of Operational Research* 98(1), pp. 19–36.

Hokkanen, J., Salminen, P. and Ettala, M. 1995. The choice of a solid waste management system using the Electre II decision-aid method. *Waste Management and Research* 13(2), pp. 175–193.

Hopfe, C.J., Augenbroe, G.L.M. and Hensen, J.L.M. 2013. Multi-criteria decision making under uncertainty in building performance assessment. *Building and Environment* 69, pp. 81–90.

Howarth, S. 2011. *Municipal Waste Management Report for Wales , 2009-10 Key results :* Cardiff, UK.

Hung, M.-L., Ma, H. and Yang, W.-F. 2007. A novel sustainable decision making model for municipal solid waste management. *Waste Management* 27(2), pp. 209–219.

Hutt, J. 2015. Welsh Government Consultation Document - Landfill Disposals Tax. , pp. 1–73.

Inda, A., Wu, J. and Zhou, D. 2014. Assessing the Hedging Value of Wind Against Natural Gas Price Volatility, Masters Thesis. Duke University.

ISO 14040 1997. ISO 14040 - Environmental Management - Life Cycle Assessment - Principles and Framework.

ISO 14041 1998. ISO 14041- Environmental management — Life cycle assessment — Goal and scope definition and inventory analysis.

ISO 14042 2006. ISO 14042 - Environmental management — Life cycle assessment — Life cycle impact assessment.

Jayasooriya, V.M. and Ng, A.W.M. 2014. Tools for Modeling of Stormwater Management and Economics of Green Infrastructure Practices: a Review. *Water, Air, & Soil Pollution* 225(8).

Jun, D., Tian-tian, F., Yi-sheng, Y. and Yu, M. 2014. Macro-site selection of wind/solar hybrid power station based on ELECTRE-II. *Renewable and Sustainable Energy Reviews* 35, pp. 194–204.

Karagiannidis, A. and Moussiopoulos, N. 1997. Application of ELECTRE III for the integrated management of municipal solid wastes in the greater Athens area. *European Journal of Operational Research* 97(3), pp. 439–449.

Keeney, R.L. and Raiffa, H. 1976. *Decisions with Multiple Objectives: Performances and Value Trade-Offs*. New York, NY, USA: Wiley.

Kijak, R. and Moy, D. 2004. A decision support framework for sustainable waste management. *Journal of Industrial Ecology* 8(3), pp. 33–50.

Kinsella, S. and Gertman, R. 2008. Single stream recycling best practices manual and implementation guide. *Progress in Paper Recycling* 17(3), pp. 6–8.

Korkmaz, A., Yanik, J., Brebu, M. and Vasile, C. 2009. Pyrolysis of the tetra pak. *Waste management (New York, N.Y.)* 29(11), pp. 2836–41.

letsrecycle 2014. Prices — letsrecycle.com - Prices [Online] Available at: http://www.letsrecycle.com/prices [Accessed: 24 July 2014].

letsrecycle 2013. WRAP changes stance on commingling [Online] Available at: http://www.letsrecycle.com/news/latest-news/waste-management/wrap-changes-stance-on-commingling.

Lindhqvist, T. 2000. Extended Producer Responsibility in Cleaner Production. Lund University.

Lindhqvist, T. and Lidgren, K. 1990. Model for Extended Producer Responsibility. *Ministry of the Environment*, pp. 7–44.

Linkov, I., Varghese, A., Jamil, S., Seager, T.., Kiker, G. and Bridges, T. 2004. Multi-Criteria Decision Analysis: A Framework for Structuring Remedial Decisions at Contaminated Sites. *Nato Science Series: IV: Earth and Environmental Sciences* 38, pp. 15–54.

Lu, D. and Realff, M.J. 2013. The Design of a Sustainability Assessment Standard Using Life Cycle Information. *Journal of Industrial Ecology* 17(4), pp. 493–503.

Lu, L. and Anderson-Cook, C.M. 2014. Balancing Multiple Criteria Incorporating Cost using Pareto Front Optimization for Split-Plot Designed Experiments. *Quality* *and Reliability Engineering International* 30(1), pp. 37–55.

Maddox, P., Doran, C., Williams, I.D. and Kus, M. 2011. The role of intergenerational influence in waste education programmes: The THAW project. *Waste Management* 31(12), pp. 2590–2600.

Mailly, D., Abi-Zeid, I. and Pepin, S. 2014. A Multi-Criteria Classification Approach for Identifying Favourable Climates for Tourism. *Journal of Multi-Criteria Decision Analysis* 21(1-2), pp. 65–75.

Manni, L.A. and Runhaar, H.A.C. 2014. The social efficiency of pay-as-you-throw schemes for municipal solid waste reduction: A cost-benefit analysis of four financial incentive schemes applied in Switzerland. *Journal of Environmental Assessment Policy and Management* 16(01).

McDonald, M. 2012. Developing a representative sample of different decision-makers. In: *Market Segmentation: How to Do It and How to Profit from It, Revised and updated 4th Edition*. 4th ed. John Wiley & Sons, pp. 143–213.

Miller, D.W. and Starr, M.K. 1969. *Executive Decisions and Operations Research*. Englewood Cliffs, NJ: Prentice-Hall.

Miranda, R., Monte, M. and Blanco, A. 2011. Impact of increased collection rates and the use of commingled collection systems on the quality of recovered paper. Part 1: increased collection rates. *Waste management (New York, N.Y.)* 31(11), pp. 2208–16.

Miranda, R., Monte, M.C. and Blanco, A. 2013. Analysis of the quality of the recovered paper from commingled collection systems. *Resources, Conservation and Recycling* 72(0), pp. 60–66.

Moore, D. 2014. Black Bag Restriction Sees 3,600-Tonne Reduction In Swansea's Waste [Online] Available at: http://www.ciwm-journal.co.uk/archives/10444 [Accessed: 16 October 2014].

Moore, D. 2015. Welsh Councils Spared Fines For Missing Recycling Targets [Online] Available at: http://www.ciwm-journal.co.uk/archives/13895 [Accessed: 12 June 2015].

Morris, J.R., Phillips, P.S. and Read, A.D. 1998. The UK Landfill Tax: an analysis of its contribution to sustainable waste management. *Resources, Conservation and Recycling* 23(4), pp. 259–270.

Ngatchou, P., Zarei, A. and El-Sharkawi, A. 2005. Pareto Multi Objective Optimization. In: *Proceedings of the 13th International Conference on, Intelligent Systems Application to Power Systems*. IEEE, pp. 84–91.

Nilsson-Djerf, J. 1999. Social factors in sustainable waste management. *Warmer Bulletin* (73), pp. 18–20.

Oakes, N. 2014a. Waste Management Engineer Private Conversation - Ceredigion County Council.

Oakes, N. 2012. Waste Management Engineer, Personal Communication - Ceredigion Counci.

Oakes, N. 2014b. Waste Management Engineer, Private Conversation - Ceredigion County Council.

Oakes, N. and Keenan, A. 2012. Waste Management Engineer & Waste Minimisation Assistant, Private Conversation - Ceredigion County Council.

De Oliveira Simonetto, E. and Borenstein, D. 2007. A decision support system for the operational planning of solid waste collection. *Waste Management* 27(10), pp. 1286–1297.

Ossadnik, W., Wilmsmann, D. and Niemann, B. 2012. Experimental evidence on case-based decision theory. *Theory and Decision* 75(2), pp. 211–232.

Pennington, D., Wolf, M.-A., Bersani, R. and Pretato, U. 2007. Overcoming barriers to the broader implementation of life cycle thinking in business and public administration. *The International Journal of Life Cycle Assessment* 12(7), pp. 458–460.

Pohekar, S.D. and Ramachandran, M. 2004. Application of multi-criteria decision making to sustainable energy planning—A review. *Renewable and Sustainable Energy Reviews* 8(4), pp. 365–381.

Quayle, P. 2014. LARAC Wales Conference 2014 [Online] Available at: http://www.larac.org.uk/news/larac-wales-conference-2014-packed-info-new-ideas-and-delegates#.VCAwxvldVls [Accessed: 10 September 2014].

Quested, T.E., Marsh, E., Stunell, D. and Parry, A.D. 2013. Spaghetti soup: The complex world of food waste behaviours. *Resources, Conservation and Recycling* 79, pp. 43–51.

R (on the application of UK Recyclate Ltd) v Secretary of State for the Environment Food and Rural Affairs 2013. [2013] EWHC 425 (Admin), [2013] 3 All ER 561 [Online] Available at: http://www.esauk.org/judicial_review_outcome/Judicial_Review_Judgment_FINAL.pdf.

Ren, J., Manzardo, A., Toniolo, S. and Scipioni, A. 2013. Sustainability of hydrogen supply chain. Part II: Prioritizing and classifying the sustainability of hydrogen supply chains based on the combination of extension theory and AHP. *International Journal of Hydrogen Energy* 38(32), pp. 13845–13855.

Roberts, C.W.G. 2014. *Report to Cabinet, 29 April 2014*.

Rodríguez, C.M. and Sánchez, P.M. 2014. Ecodesign: A Strategy of Solid Waste (Packaging) Reduction at Universidad El Bosque. In: *The 29th International Conference on Solid Waste Technology and Management, 30 March - 2 April*. Philadelphia, PA, USA, pp. 128–138.

Roy, B. 1968. Classement et choix en présence de points de vue multiples (La méthode ELECTRE). *RAIRO - Operations Research - Recherche Opérationnelle* 2(V1), pp. 57–75.

Roy, B. 1990. Decision-aid and decision-making. In: *Readings in Multiple Criteria Decision Aid*. Springer Berlin / Heidelberg, pp. 17–35.

Roy, B. 1991. The outranking approach and the foundations of electre methods. *Theory and Decision* 31(1), pp. 49–73.

Saaty, T.L. 2002. Decision making with the Analytic Hierarchy Process. *Scientia Iranica* 9(3), pp. 215–229.

Saaty, T.L. 2003. Decision-making with the AHP: Why is the principal eigenvector necessary. *European Journal of Operational Research* 145(1), pp. 85–91.

Saaty, T.L. 2000. *Fundamentals of Decision Making and Priority Theory With the Analytic Hierarchy Process*. RWS Publications.

Saaty, T.L. 2002. Hard Mathematics Applied to Soft Decisions. In: *Indonesian Symposium Analytic Hierarchy Process II Teknik Industri Universitas Kristen Petra Surabaya*. Surabaya: Universitas Kristen Petra.

Saaty, T.L. 1994. How to Make a Decision: The Analytic Hierarchy Process. *Interfaces* 24(6), pp. 19–43.

Saaty, T.L. 1980. The Analytic Hierarchy Process. In: McGraw Hill International, pp. 3–37.

Saaty, T.L. and Ozdemir, M.S. 2003. Why the magic number seven plus or minus two. *Mathematical and Computer Modelling* 38(3–4), pp. 233–244.

Saaty, T.L. and Sagir, M. 2009. An essay on rank preservation and reversal. *Mathematical and Computer Modelling* 49(5-6), pp. 1230–1243.

Sanchez Reinoso, C.R., De Paula, M. and Buitrago, R.H. 2014. Cost–benefit analysis of a photovoltaic power plant. *International Journal of Hydrogen Energy* 39(16), pp. 8708–8711.

Sánchez-Lozano, J.M., Henggeler Antunes, C., García-Cascales, M.S. and Dias, L.C. 2014. GIS-based photovoltaic solar farms site selection using ELECTRE-TRI: Evaluating the case for Torre Pacheco, Murcia, Southeast of Spain. *Renewable Energy* 66, pp. 478–494.

Sauter, V.L. 1997. *Decision Support Systems: an applied managerial approach*. New York : John Wiley.

Schramm, F. and Morais, D.C. 2012. Decision support model for selecting and evaluating suppliers in the construction industry. *Pesquisa Operacional* 32(3), pp. 643–662.

Siegmeier, T., Blumenstein, B. and Möller, D. 2015. Farm biogas production in organic agriculture: System implications. *Agricultural Systems* 139, pp. 196–209.

Statistics for Wales 2014. *Local authority municipal waste management report for Wales, 2012-13*. Cardiff.

StatsWales 2011. 2011 Census: Welsh residents by sex [Online] Available at: https://statswales.wales.gov.uk/Catalogue/Census/2011/WelshResidents-by-Gender-LocalAuthority [Accessed: 24 October 2014].

StatsWales 2014a. Annual Local Authority Municipal Waste [Online] Available at: https://statswales.wales.gov.uk/Catalogue/Environment-and-Countryside/Waste-Management/Local-Authority-Municipal-Waste/Annual.

StatsWales 2014b. Percentage reuse/recycling/composting rates by local authority and year [Online] Available at: https://statswales.wales.gov.uk/Catalogue/Environment-and-Countryside/Waste-Management/Local-Authority-Municipal-Waste/Annual/Pre-April 2012-definition/PercentageReuseRecyclingCompostingRates-by-LocalAuthority-Year [Accessed: 24 September 2014].

Stefanidis, S. and Stathis, D. 2013. Assessment of flood hazard based on natural and anthropogenic factors using analytic hierarchy process (AHP). *Natural Hazards* 68(2), pp. 569–585.

Summerfield, C. and Tsetsos, K. 2014. Do humans make good decisions? *Trends in Cognitive Sciences* 19(1), pp. 27–34.

Sword, H. 2013. Dancing on the bottom line: an unruly cost–benefit analysis of three academic development initiatives. *Higher Education Research & Development* 33(4), pp. 783–793.

Tan, R.R. and Promentilla, M.A.B. 2012. A methodology for augmenting sparse pairwise comparison matrices in AHP: applications to energy systems. *Clean Technologies and Environmental Policy* 15(4), pp. 713–719.

Tong, O., Shao, S., Zhang, Y., Chen, Y., Liu, S.L. and Zhang, S.S. 2012. An AHP-based water-conservation and waste-reduction indicator system for cleaner production of textile-printing industry in China and technique integration. *Clean Technologies and Environmental Policy* 14(5), pp. 857–868.

Triantaphyllou, E. 2000. Multi-Criteria Decision Making Methods: A Comparative Study. In: Dordrecht: Kluwer Academic Publishers, pp. 6–9.

Triantaphyllou, E. and Baig, K. 2005. The Impact of Aggregating Benefit and Cost Criteria in Four MCDA Methods. *IEEE Transactions on Engineering Management* 52(2), pp. 213–226.

Tulokhonova, A. and Ulanova, O. 2013. Assessment of municipal solid waste management scenarios in Irkutsk (Russia) using a life cycle assessment-integrated waste management model. *Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA* 31(5), pp. 475–84.

Tunesi, S. 2011. LCA of local strategies for energy recovery from waste in England, applied to a large municipal flow. *Waste Management* 31(3), pp. 561–571.

Turban, E., Sharda, R. and Delen, D. 2010. *Decision Support and Business Intelligence Systems*. 9th ed. Upper Saddle River, NJ, USA: Prentice Hall Press.

UNFCCC 1997. *Kyoto Protocol to the United Nations Framework Convention on Climate Change adopted at COP3 in Kyoto, Japan, on 11 December 1997*.

United Nations 2013. *World Population Prospects The 2012 Revision*. New York: United Nations.

Vorobyov, S.A., Wang, C.X. and Thompson, J. 2012. Pareto Region Characterization for Rate Control in MIMO Interference Systems and Nash Bargaining. *IEEE Transactions on Automatic Control* 57(12), pp. 3203–3208.

WAG 2009. Towards Zero Waste – One Wales : One Planet Strategy, W. ed.

WAG 2002. Wise About Waste – The National Waste Strategy for Wales Division, E. P. ed.

Wang, F.S. 2001. Deterministic and Stochastic Simulations for Solid Waste Collection Systems – A SWIM Approach. *Environmental Modeling and Assessment* 6(4), pp. 249–260.

Wang, F.S., Richardson, A.J. and Roddick, F.A. 1996. SWIM - a computer model for solid waste integrated management. *Computers, Environment and Urban Systems* 20(4-5), pp. 233–246.

Wang, J.-J., Jing, Y.-Y., Zhang, C.-F. and Zhao, J.-H. 2009. Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews* 13(9), pp. 2263–2278.

Waste Awareness Wales and AEA 2011. *Barriers to Recycling*.

Wei, L. and Yuying, Y. 2008. Multi-objective optimization of sheet metal forming process using Pareto-based genetic algorithm. *Journal of Materials Processing Technology* 208(1-3), pp. 499–506.

Welsh Government 2014. Consultation on Draft Statutory Guidance on Separate Collection of Waste Paper, Metal, Plastic and Glass.

Welsh Government 2010. *Waste (Wales) Measure 2010*. Wales.

Wheeler, N. 2012. Service Director for Street-Care, Private Consultation - Rhondda Cynon Taf County Borough Council.

Wikimedia 2014. Image - Ceredigion Constituency [Online] Available at: http://commons.wikimedia.org/wiki/Category:Maps_of_Ceredigion [Accessed: 24 October 2014].

Williams, P. 2014. *Commission on Public Service Governance and Delivery - Summary Report*.

Wilsnack, M.M., Doherty, J.E. and Welter, D.E. 2012. Pareto-Based Methodology for the Calibration and Uncertainty Analysis of Gated Culvert Flows. *Journal of Irrigation and Drainage Engineering* 138(7), pp. 675–684.

Wilson, C.D.H. and Williams, I.D. 2007. Kerbside collection: A case study from the north-west of England. *Resources, Conservation and Recycling* 52(2), pp. 381–394.

WRAP 2008. *Kerbside recycling: indicative costs and performance*. Banbury, Oxon, UK.

WRAP 2014. *Sampling and Testing Guidance for Material Facilities*.

WRAP 2006. *The CO2 emissions estimator tool for the use of aggregates in construction. User guide volume 1.0*. ISBN: 1-84. Banbury, Oxon, UK: WRAP.

WYG-Environment 2012. *Review of kerbside recycling collection schemes in the UK in 2010/11*.

Xie, M., Qiao, Q., Sun, Q. and Zhang, L. 2013. Life cycle assessment of composite packaging waste management - A Chinese case study on aseptic packaging. *International Journal of Life Cycle Assessment* 18(3), pp. 626–635.

Zimmermann, H.-J. 1990. Decision Making in Ill-Structured Environments and with Multiple Criteria. In: Bana e Costa, C. A. ed. *Readings in Multiple Criteria Decision Aid*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 119–151.

8. Appendices

8.1 Appendix 1 – Studentship Agreement

Studentship Agreement

THIS AGREEMENT is made on the 3[rd] day of October, 2011

is made BETWEEN:

(1) **CARDIFF UNIVERSITY**, established under royal charter whose registered charity number is 1136855 and whose administrative offices are at 30-36 Newport Road, Cardiff, CF24 0DE, U.K. (the "University"); and

(2) **CERIDIGION COUNTY COUNCIL with administrative offices at market Street, Aberaeron, Cerdigion** (the "Co-operating Body"); and

(3) **ALEXANDER DAVIES** of Flat 4, Cadogan Court , Cardiff, CF24 4EN student registration number 0609984 (the "Student")

together the "Parties" and each a "Party".

RECITALS

The Co-operating Body is willing to part fund in conjunction with the University a studentship project upon the terms and conditions set out below.

WHEREAS the Parties hereby agree:

1. Definitions

In this Agreement the following words shall have the following meanings unless the context otherwise requires:

"Confidential Information"	any information which has been designated as confidential by either Party in writing or that ought to be considered as confidential (however it is conveyed or on whatever media it is stored) including without limitation information which relates to the business, affairs, properties, assets, trading practices, services, developments, trade secrets, Intellectual Property rights, know-how, personnel, customers and suppliers of either Party, all personal data and sensitive personal data within the meaning of the Data Protection Act 1998.;
"Intellectual Property"	all and any rights in or to inventions, patents, utility models, registered designs, trade marks, applications for any of the foregoing together with the right to apply therefor in any part of the world; copyrights, rights in the nature of copyright, database rights, design rights including unregistered Community designs; trade names, logos; trade secrets, confidential information, know-how; and all similar or equivalent rights arising or subsisting in any part of the world;
"Project"	shall mean the project details of which as set out at Schedule 1 hereto;
"Project Period"	shall mean from 1st October 2011 to 30th September 2014;
"Project Fees"	shall mean the fees payable by the Co-operating Body to the

	University set out at Schedule 2 hereto;
"Results"	the results developed by the Student and/or the University from the performance of the Project together with all Intellectual Property therein;
"Supervisors"	Professor Anthony Griffiths and Dr Steven Bentley together with such successor as may be appointed by the University from time to time.

2. The Project

2.1 The Project shall run for the Project Period.

2.2 The Project will be undertaken by the Student under the direction and supervision of the Supervisor, and will be conducted partly in the laboratories of the University and partly on the premises of the Co-operating Body.

2.3 The Co-operating Body will allow the Student to attend its research establishments during the Project Period and for the purpose of the Project, and in consultation with the Supervisor will designate an industrial research scientist to provide the Student with advice and guidance. The periods of such attendance will be scheduled by mutual agreement. The Student shall comply with all works rules and safety and other regulations which the Co-operating Body may reasonably notify to the Student during those periods.

3. Funding by the Co-operating Body

3.1 The Co-operating Body shall pay the University the Project Fees set out in Schedule 2.

3.2 In addition to payment of the Project Fees, the Co-operating Body will pay to the University within 30 days after the date of invoice an amount equal to all expenses, including the cost of travel and accommodation, which are reasonably incurred by the Student and the Supervisor as a direct result of attendance at the premises of the Co-operating Body pursuant to this Agreement.

4. Intellectual Property and use of the Results

4.1 [The Co-operating Body and the Student hereby agree that all Results shall belong to and vest in the University, save that any copyright in the thesis produced by the Student shall remain with the Student, and the Co-operating Body and the Student hereby assign to the University all of their right, title and interest in and to the Results (other than such copyright in such thesis).

4.2 Subject always to Clause 4.4, the University hereby grants or agrees to grant to the Co-operating Body a non-exclusive, licence to use any and all of the Results for its commercial purposes. Such licence does not include any right to assign, sub-licence or otherwise transfer or dispose of the rights contained therein without the prior written consent of the University.

4.3 The University hereby grants the Co-operating Body an option to negotiate an exclusive licence to use the Results for commercial purposes. Such licence shall be upon fair and reasonable commercial terms and shall be subject to Clause 4.4. The option shall run for a period of 9 months following the end of the Project Period and during this time the University shall enter into good faith negotiations upon exercise of such option by the Co-operating Body.

4.4 The Parties agree that in respect of any revenue generated or received by or on behalf of the Co-operating body through or as a result of any use exploitation, assignment, sub-licence or transfer of the Results pursuant to:

4.4.1 the non-exclusive licence contained within Clause 4.2; and/or

4.4.2 any exclusive licence granted to the Co-operating body pursuant to Clause 4.3

the Co-operating Body shall account to the University for a fair and reasonable proportion of such revenue. Factors that shall be considered in determining what constitutes a fair and reasonable proportion of such revenue shall include without limitation the respective financial and intellectual contribution of the University (which for the avoidance of doubt and without limitation shall include the contribution of the Student) and the Co-operating Body to the generation, maintenance and exploitation of the relevant Results.

5. Publications

5.1 The Co-operating Body recognises that the Project will form part of the performance of the University's primary charitable purpose; that is, the advancement of education through teaching and research. Accordingly and in compliance with University policy, the Results must be publishable by the Student and/or the University.

5.2 The Student and/or the University agree to provide the Co-operating Body with a copy of any proposed publication relating to the Project at least thirty (30) days prior to submission for publication. The Co-operating Body may object to publication by providing notice to the Student and the University on the basis that:

5.2.1 the publication contains any Confidential Information of the Co-Operating Body.

PROVIDED THAT if the Student and the University have not received notice from the Co-operating Body objecting to the publication within twenty (20) days of receiving a copy of the proposed publication the Co-operating Body shall be deemed to have agreed to the publication and the Student and/or the University (as the case may be) may proceed with the publication.

5.3 If the Co-operating Body objects to any proposed publication notified to it under Clause [5.2] on the basis the publication contains Confidential Information of the Co-Operating Body, the Co-operating Body shall identify such Confidential Information and the Student and/or the University shall remove such Confidential Information from the publication

5.4 It is further agreed by the Student and/or the University that, at the Co-operating Body's request, an acknowledgement to the Co-operating Body be included on any written publication produced by the Student and/or the University in recognition of the Co-operating Body's involvement in the Project.

6. Confidentiality

6.1 Each Party shall treat as strictly confidential the Confidential Information belonging to the other Parties and shall:

6.1.1 use the same only for the purposes of this Agreement;

6.1.2 not disclose the same to any person other than as permitted pursuant to the terms of this Agreement.

6.2 In the event of a Party visiting the establishment of another Party, the visiting Party undertakes that any further Confidential Information relating to other Parties research projects which may come to the visiting Party's knowledge as a result of any such visit, shall be kept strictly confidential and that any such Confidential Information will not be disclosed to any third party or made use of in any way by the visiting Party without prior written permission of the other Party.

6.3 Each Party shall restrict access to the Confidential Information belonging to another Party on a 'need-to-know basis' and shall ensure that any employees, students and consultants to whom Confidential Information is disclosed hold the Confidential Information upon conditions of secrecy as set out in this Agreement.

6.4 The provisions of this Clause [6] shall not apply to any Confidential Information:

6.4.1 which at the time of receipt by a Party is in the public domain; or

6.4.2 is published or generally available to the public through no fault of the receiving Party, its employees or consultants; or

6.4.3 is in the possession of the receiving Party prior to the date of this Agreement and which is not subject to a duty of confidentiality; or

6.4.4 is independently developed by the receiving Party and which is not subject to a duty of confidentiality; or

6.4.5 which after its receipt by a Party is made public by a third party acting without impropriety in so doing.

6.5 The obligations of confidentiality set forth in this Clause [6] shall not apply to any Confidential Information to the extent it is required to be disclosed by applicable law, an order of a court of law or by a supervisory or regulatory body to whose rules the receiving Party is subject or with whose rules it is necessary for the receiving Party to comply, provided that the receiving Party shall inform the disclosing Party as soon as possible and the disclosing Party be given the opportunity, if time permits, to make appropriate representations or take such action as it feels necessary, at its cost, to attempt to prevent or limit the disclosure of such Confidential Information.

6.6 Subject to the obligations of confidentiality contained in this Clause [6], nothing in this Agreement shall prevent any registered student of the University from submitting for a degree of the University a thesis based on the results obtained during the course of work undertaken as part of the Project, the examination of such a thesis by examiners appointed by the University, or the deposit of such a thesis in a library of the University in accordance with the relevant procedures of the University and accordingly the Co-operating Body hereby grants or agrees to grant to the Student, the Supervisor and the University a licence to use the Intellectual Property in the Results for such purposes.

7. Liability

7.1 Each Party shall be responsible for and liable in respect of any and all use and reliance which that Party may make of or place on the Results, any Confidential Information and/or other advice or communication received in connection with the Project.

7.2 The Parties each acknowledge that, in entering into this Agreement, it does not do so in reliance on any representation or warranty given by any other Party and any conditions, warranties or other terms implied by statue or common law are excluded from this Agreement to the fullest extent permitted by law. Accordingly, each Party acknowledges and accepts that no other Party makes any warranties or representations whether express or implied regarding the Results and, without limitation, no warranty nor representation is given that:

7.2.1 the Results and/or use of the same will not infringe the rights of any person; or

7.2.2 the Project will be successful or that any particular result or objective shall be achieved, be achievable or be attained at all or by expiry of the Project Period or by any other date.

7.3 No Party shall be liable to another in connection with this Agreement and/or the Project whether under contract, tort, negligence, breach of statutory duty or otherwise for any:

7.3.1 loss of contracts, loss of goodwill, loss of opportunity, loss of profits, loss of turnover or loss of anticipated savings; or

7.3.2 indirect or consequential loss or special loss or damage of any nature whatsoever.

8. Force majeure

8.1 If the performance by any Party of any of its obligations under this Agreement (other than an obligation to make payment) shall be prevented by circumstances beyond its reasonable control, then such Party shall be excused from performance of that obligation for the duration of the relevant event.

9. Term and Termination

9.1 This Agreement shall be deemed to have commenced at the start of the Project Period and shall continue in full force and effect until expiry of the Project Period unless terminated earlier pursuant to the provisions of this Clause [9].

9.2 This Agreement may be terminated by either the University or the Co-operating Body for any material breach of the obligations set out in this Agreement, by giving 90 days' written notice to the other of its intention to terminate. The notice shall include a detailed statement describing the nature of the breach. If the breach is capable of being remedied and is remedied within the 90-day notice period, then the termination shall not take effect. If the breach is incapable of remedy, then the termination shall take effect at the end of the 90-day notice period in any event.

9.3 In the event that the Student or any replacement student withdraws from the Project before the expiration of the Project Period, and the University is not able to recruit a suitable alternative within three (3) months, the Agreement shall terminate forthwith on the expiry of the three (3) months. Upon such termination, the University shall make a repayment to the Co-operating Body in respect of any Project Fees already made by the Co-operating Body in accordance with Schedule 2, such repayment being pro rata from the date on which such student withdraws from the Project to the end of the period for which fees have been paid.

9.4 In the event the Student withdraws from the Project all rights of the Student pursuant to this Agreement shall cease with effect from the date of such withdrawal and all future obligations of the Student shall also cease with the exception of the obligations of the Student contained within the Clauses referred to in Clause [9.7], which shall survive such withdrawal.

9.5 The Student's involvement in the Project shall terminate upon the Student's withdrawal. Any future amendment to this Agreement after such withdrawal shall be effective if signed by the University and the Co-Operating Body. The University shall take all reasonable steps to procure that a replacement student accepts of all those obligations expressed to be of the Student under this Agreement.

9.6 Upon expiry or termination of this Agreement all rights and obligations of the Parties shall, subject to the provisions of Clause [9.7], immediately cease without prejudice to any rights of action then accrued hereunder or at law.

9.7 The following provisions shall survive expiry or termination of this Agreement howsoever arising: Clauses [4, 5, 6, 7, 9.7, 11 and 14].

10. Reports

10.1 The University will use reasonable endeavours to provide the Co-operating Body with annual reports summarising the progress of the Project.

11. Publicity

11.1 No Party shall use the name of either of the others in any press release or product advertising, or for any other commercial purpose, without that other Party's prior written consent; provided, however, that publication of the sums received from the Co-operating Body in the University's annual report and similar publications shall not be regarded as a breach of this Clause [11.1].

12. Assignment

12.1 None of the other Parties shall assign or sub-contract any of its rights and obligations under this Agreement without the prior written consent of the other Parties.

13. Notices

13.1 The University's representative for the purpose of receiving notices shall until further notice be:

> The Director of Research & Commercial Division, Cardiff University, 30-36 Newport Road, Cardiff, CF24 0DE.

13.2 The Co-operating Body's representative for the purpose of receiving invoices, reports and other notices shall until further notice be:

Nr Nick Oakes of the address set out above.

14. General

14.1 Nothing in this Agreement shall create, imply or evidence any partnership or joint venture between the Parties or the relationship between any of them of either principal and agent or employer and employee.

14.2 This Agreement, and its Schedules (which are incorporated into and made a part of this Agreement), together constitute the entire agreement between the Parties for the Project. Any variation shall be in writing and signed by all Parties or by their authorised signatories.

14.3 This Agreement shall be governed by the laws of England & Wales. The courts of England & Wales shall have exclusive jurisdiction to deal with any dispute which has arisen or may arise out of or in connection with this Agreement.

14.4 The Parties do not intend that the terms of this Agreement create any right enforceable by any person who is not a party to it under the Contracts (Rights of Third Parties) Act 1999 (the "Act") or otherwise.

AGREED by the Parties through their authorised signatories:

For and on behalf of Cardiff University	For and on behalf of Ceridigion County Council
Geraint W Jones	X Huw T. Morgan X
signed	signed
	Huw T. Morgan
print name Geraint W. Jones Director Research and Commercial Division	print name HUW MORGAN
title 3 October, 2011.	title Director of Highways, Property and Works
date	date X Sept. 28th, 2011 X

By the Student

A R Davies

Signed and dated 3rd Oct 2011

SCHEDULE ONE

The Project

Factors and Influences Affecting Recycling Targets

Background
Wales is the first country in the UK to adopt statutory recycling targets for municipal solid waste (MSW). The Welsh Assembly Government (WAG) has set challenging recycling targets within its waste strategy 'Towards Zero Waste', which requires a minimum of 52% of MSW collected by local authorities to be prepared for reuse and recycled/composted by 2012-2013, rising to 70% by 2024/25. WAG are using these targets to meet the Landfill Directive that is based on Biodegradable Municipal Waste (BMW). However, many authorities are affectively tackling the household component of MSW only which means for many it will be difficult to achieve these targets and hence will face a financial burden.

The key priority materials are food waste, plastic and paper, which have been identified as those with the highest ecological footprint. This means that many of the current systems in place could have a major impact on the local authority's carbon footprint. The classical impact is the transportation difficulties that rural authorities face when compared to their urban counterparts. WAG can impose fines on authorities which fail to meet the targets and current proposals suggest a fine of £200 for every tonne that a local authority falls short of their target amount. The Landfill Allowance Scheme (LAS) targeting BMW for local authorities uses similar penalty structures; however, there may be a move towards abolishing LAS in favour of the "Towards Zero Waste" direction. Hence as more stringent regime for authorities to comply with.

As a consequence, there will be significant pressure (financial, social and political) for local authorities in Wales to drive up their recycling performance to meet the targets. In order to achieve these targets, they need to identify factors and influences that affect their particular recycling regimes. These could be barriers based on local conditions and can broadly be grouped into people, service and infrastructure, geography, political, economic, and communications. This is also being distorted by the WAG's drive to see Anaerobic Digestion (AD) and kerbside sort as a preferred route. For many the latter is an impractical solution. AD has merits, but the drive by WAG to have so called "hubs" may in fact significantly impact on the authority's carbon footprint.
Figure 1 highlights the typical strategy adopted by many local authorities in meeting its recycling targets. Generally this would include either kerbside sort or collection, household waste recycling centres (HWRC) and bring sites.

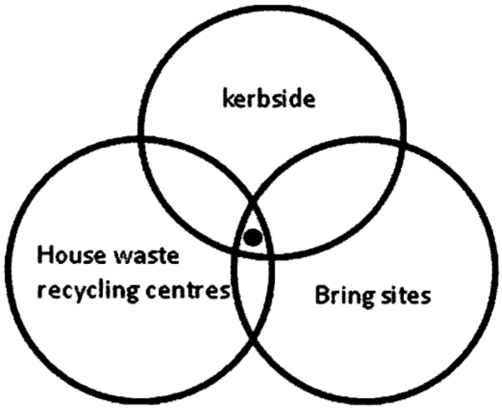


Figure 1 Typical Activities Employed by Authorities to Recycle

House Hold Waste

The most successful of the authorities utilises all three based on the local conditions and the Venn diagram shown in figure 1 can be distorted to achieve the strategy. The central portion (blue dot) is where maximum benefit can be achieved.
Areas that are not taken into consideration is the benefit that activities such as:

- Home composting
- Voluntary sector/not for profit organisations – e.g. furniture recycling
- Charity shops.
- Supermarket recycling

All play a vital role within a community and add benefit to many social groups. However the impact on and interaction with targets is not considered. There has been much discussion on the above, but no definitive answer has been put forward. For example in the rural environment home composting may be significant but authorities not see the benefit. Many supermarkets have their own recycling schemes to comply with regulations they have to comply with, however this could be a potential conflict with authorities since they may be taking away prime recycling material from the waste stream that cannot be accounted for in waste flow data analysis.

The Proposal
Most authorities are a stage where either large scale investment or issuing of tender documents for particular recycling/processing operations are required to meet targets beyond 2012. Both routes have a major impact on the authority's ability to deliver WAG targets. Due to the confusion in the acceptable directions that Wag would prefer then to take, there has been a reluctance to invest. The "towards Zero Waste" strategy will impinge on a range of routes that an authority may consider. Therefore a mapping exercise of the practical management implications of delivering zero waste policies will be considered. This will involve analysis of the interactions authorities have with local service providers in the waste recycling field. This involve routes shown in figure 1 as well as the private, voluntary and "not for profit" communities. Barriers, identifying factors and influences for the following thematic areas will be analysed:

- Infrastructure and service delivery

- Geography and situation – including physical barriers
- Political issues and barriers
- Population / people – including psychological barriers
- Communication issues and barriers
- Economic issues and barriers
- Material specific issues/barriers

The latter area is of politic interest, since WAG are encouraging authorities to develop specific material recycling such as mattresses. But this is a very difficult stream to recycle due to its large investment requirement and relatively low through put.

Beyond 2024/25 the drive is to have zero landfill which requires a further strategy change in terms of a stronger reliance of both AD for non-food based BMW and "Energy from Waste" systems, such as advanced thermal systems involving gasification and/or pyrolysis will be required. These two processes will be feed stock sensitive and will be impacted on by the strategy and processes in place/being developed to meet future targets. Hence a detailed study to provide an in site in the change of waste composition as strategies and targets are introduced and analyse the most effective way of meeting these changes. Hence an holistic approach to waste management where all sectors of the community play their part in meeting "zero landfill".
A combination of the barriers highlighted above will be analysed in terms of the socio-economic groups in a particular authority and how develop a route map in how this can be developed for particular sectors.

Other areas where the research direction is important are as follows:

1. Commercial & Industrial (C&I)and Construction and Demolition (C&D) waste – a study to identify practical ways to assist authorities to integrate their collection and management of household and C&I and C&D waste, without falling foul of the different regulatory regimes for the different waste streams. Again this will eventually be driven by WAG in terms of their specific stream directions.
2. The review of Incentives to recycle and how they would work in either a rural or urban environment.
3. To analyse in the contact of the rural and urban environments the benefits or otherwise of Kerbside sort verses large scale comingle collections. This would be from both an authority and recycling operator point of view.
4. Critical review of the "Zero Waste" strategy. The reality and the role of society towards zero waste issues. Addressing the impact and implications that both the private and public sector has on delivery as well as analysing the barriers such as political, economic, social and institutional will have on the road map that an authority may need to develop to meets WAGs long term onjectives.
5. The role of social network on waste management industry and public perception: explore how social network can be used as a tool for behaviour change.
6. Approaches to achieve waste minimisation and carbon reduction to meet the reductions in the carbon footprint
7. The role of AD by-product in meeting future targets – Analysis of introduction of AD plants and the impact based on either small scale or hub scale as preferred by WAG. The use of the by products in terms of Combined Heat and Power or as a localised fuel sources will be addressed. Quality and acceptability of the products into the market place using PAS 110 for example, possibly development of different grades of the product will be another study area. Generally green waste composting has been around for about a decade, but its acceptability in

the market place is still low. The encouragement of landscape specification for such products has been seen as a distinct barrier.

8. The role of recycling is only as good as the current market place for accepting recyclates. Currently a large percentage is exported. This is seen as being unsustainable in the long term and currently creates a fickle and volatile market place. A detailed study considering the Welsh and UK secondary processing sector will be undertaken with a view to determine underling trends and uncertainties. Glass and waste wood are classic examples where a few years ago recyclers were commanding reasonable prices, however today it's a negative outgoing and hence the private sector is reluctant to offer collection facilities unless charges are incurred.

The Direction

In 2000 the author along with a colleague Professor Keith Williams put forward this integrated structure to WAG as shown in figure 2. As you can imagine at that time this was not seen in a very good light due to the addition of energy within the process stream. There has now been a change of view, however the point of highlighting figure 2 is the fact that in the opinion of the authors that a 93 % reduction was achievable, but required willpower, imagination and clear directions. The last 7% is the difficult part, although not required to be solved now it will require some long term thinking and strategy that may be outside of the normal political cycle.

The research themes highlighted in the proposal were set to give an indication that much more studies are required to provide results, data and information to key decision makers so that more confidence can be gained when selected particular route maps and strategies. The areas identified require a large amount of research man years to tackle/study the vital issues. The proposal has been developed so that particular directions may be selected that will suit that particular organisation or authority and hence achieve value for money. The author has worked with many authorities and organisations specific to the waste/recycling sector.

Professor A J Griffiths CEng PhD BEng FIMechE MIET SWIE
15th April 2011

8.2 Appendix 2 – University Ethical Policy

Ethical Approval of Research with Human Participants, Human Material or Human Data within the School of Engineering at Cardiff University

Background

In 2003, following a review of the existing University procedures for research management and for considering ethical aspects of research, it was decided by the University Research Committee that a more consistent approach should be adopted throughout the University. The University now requires that all non-clinical research involving human participants or human material or human data is subject to formal ethical review and approval before such work can be started.

Who does it apply to?

This guidance applies to all staff and students in the School of Engineering undertaking research in their capacity as members of Cardiff University.

In the case of students, it covers research undertaken by a student currently registered for a degree within the School as a recognised part of his or her degree programme. However, it does not apply to work carried out as part of the teaching of the programme, for example, students conducting established experiments as part of their learning.

In respect of non-student research, the University policy of ethical review and approval of non-clinical research with human participants, human material or human data applies to all individuals carrying out research under the aegis of Cardiff University. This includes all University employees, whether the work is undertaken within or outside University premises and all visiting researchers of the University irrespective of whether they are employed by the University, including persons with honorary positions, conducting research within, or on behalf of, the University.

What research does it cover?

This guidance covers all non-clinical research involving human participants or human material or human data (clinical research is referred to NHS ethics committees for approval). It applies whether the research is funded or not and whatever the source of funding.

The ethical review process does not include research where the information about human participants is publicly and lawfully available, e.g. information published in the census, population statistics published by government departments, personal letters, diaries etc held in public libraries.

Non-clinical human research in this context is taken to be research which is generally not concerned with medical treatment of patients but which applies systematic procedures of investigation to human beings, human material and human data, whatever the nature of the research; whether, for example, it be biological, social or psychological.

Research involving the following must be referred to a NHS research ethics committee:

(a) patients and users of the NHS. This is intended to mean all potential research participants recruited by virtue of the patient or user's past or present treatment by, or use of, the NHS. It includes NHS patients treated under contracts with private sector institutions;

(b) individuals identified as potential research participants because of their status as relatives or carers of patients and users of the NHS, as defined above;

(c) access to data, organs or other bodily material of past and present NHS patients;

(d) foetal material and IVF involving NHS patients;

(e) the recently dead in NHS premises;

(f) the use of, or potential access to, NHS premises or facilities;

(g) NHS staff recruited as research participants by virtue of their professional role.

Neither School nor University Research Ethics Committees are empowered to give permission for researchers to conduct research involving any of the above. Although it is expected that non-clinical research involving any of these categories would be rare, where such research is proposed the researchers must apply to the relevant NHS research ethics committee. Making such application is the responsibility of the principal researcher. In cases of doubt, applicants should contact the secretary to the University Research Ethics Committee for further guidance.

How do I get approval for a project?

If you are planning a project that involves human participants, human data or human materials, you will need to get ethical approval. You will receive this approval by completing a pro-forma that gives details of your research and any related ethical issues, and submitting your application by one of two routes: either via the School Research Committee, which will deal with staff and PGR projects and act on recommendations from the School Ethics Officer; or alternatively, for UG and PGT students, by submitting an application direct to the School Ethics Officer, who will approve or reject proposals and report outcomes to the Research Committee.

The procedure for making an application is provided in the Appendices. Pro-formas for applying for ethical approval can be obtained from the ENGIN Research Office.

Role of the School Ethics Officer

The School of Engineering has designated a School Ethics Officer responsible for the management of ethical issues in research in the School. The responsibilities of the School Ethics Officer are as follows:

(a) ensuring that there are effective mechanisms to bring any policy, guidelines or procedures developed with or through the University Research Ethics Committee and the School Research Committee to the attention of staff and students for whom the School is responsible. These mechanisms are intended to clarify that it is a University requirement that these policies, guidelines and procedures are followed;

(b) keeping School ethical issues in research under review;

(c) managing and monitoring the procedures in practice;

(d) ensuring that appropriate records of applications, practices and decisions are made and kept;

(f) reporting to the School through the Research Committee;

(g) reporting on an annual basis on behalf of the School to the University Research Ethics Committee;

(h) conducting a three yearly review of School ethical procedures and reporting the outcome to the University Research Ethics Committee;

(i) being eligible for membership of the University Research Ethics Committee which entails attending meetings of the University Research Ethics Committee and dealing with the work of that Committee.

The contact details for the School Ethics Officer are given below.

Role of School Research Committee

The School Ethics Officer will report to the ENGIN Research Committee. The Research Committee will receive applications for ethical approval with recommendations on approval from the School Ethics Officer.

Terms of Reference

The terms of reference of the Research Committee in relation to ethical approval and in conjunction with the School Ethics Officer are:

(a) to consider non-clinical research proposals from staff and PGR students involving human participants, human material or human data;

(b) to receive reports of UG and PGT projects involving human participants, human material or human data that have been approved by the School Ethics Officer;

(c) to either give written approval for staff/PGR proposals in the form of minutes or provide written information as to why approval has not been given;

(d) to consider revised submissions;

(e) to refer to the University Research Ethics Committee cases which cannot be satisfactorily resolved or about which there is uncertainty;

(f) to operate procedures no less rigorous than those suggested or required by relevant professional bodies or other organisations in the subject domain (e.g. sponsoring bodies).

(g) to inform the University Research Ethics Committee of any changes in the ethical codes of professional bodies in relevant discipline areas, in order that the University's procedures remain valid.

Operation of the Research Committee in relation to ethical approval procedures

i) Staff and PGR Projects

The Committee will consider applications for ethical approval of projects and the recommendations of the School Ethics Officer.

The project will be either approved as it stands, accepted subject to specified alterations, or rejected. If your project is approved subject to specified alterations, you may not proceed to start the research until these changes have been approved by the Research Committee.

Any recommendations and/or revisions will be recorded. Following the meeting, the Secretary will draft a response for each application including the decisions of the Committee and any revisions required. Responses will be approved by the Chair/Convenor before being returned to the applicant and, in the case of research student projects, the supervisor.

Proposals approved by the Committee may commence immediately. In the case of proposals subject to recommendations and revisions, researchers will be given details of the required alterations and must confirm that such alterations have been made, in writing, to the Committee Secretary, prior to the next meeting. Revised proposals will be approved, on the recommendation of the School Ethics Officer, at the next meeting.

ii) UG and PGT Projects

In order to process UG and PGT projects in a timely fashion, such projects may be approved by the School Ethics Officer. If the School Ethics Officer is satisfied that the proposal raises no ethical issues, the project may go ahead. However, if the School Ethics Officer believes that there are ethical issues, the project must be referred to the Research Committee.

UG and PGT students should complete an ethical approval pro-forma, to be signed off by the School Ethics Officer. Copies of approved applications should be submitted to the Secretary to Research Committee in order to be reported the Committee.

Membership

As per usual Research Committee membership, plus the School Research Ethics Officer :

Prof P J Tasker (Chair)

Prof H R Thomas (HoS)

Prof R A Falconer

Prof D Jiles

Prof L D M Nokes

Prof J A Chambers

Prof J C Miles

Prof B L Karihaloo

Dr D Kennedy

Dr A Porch

Dr K M Holford

Dr L Bartlett

Prof P N T Wells (School Ethics Officer)

Mrs P Donovan

Mrs J McMillan

Mrs F Pac-Soo

Ms C Summers

Mrs S Stockman (Secretary)

Decisions on ethical approval

The School Ethics Officer and the Research Committee will make decisions on ethical approval based on the information provided by the applicant. The Committee is guided by the University's policy on ethical research and by relevant professional body guidelines and legal requirements.

The pro-forma for applying for ethical approval of projects is designed to highlight any potential ethical problems arising from the proposed research, but the researcher also has a duty to raise any additional ethical issues for consideration by the SEO and the Research Committee.

Timing

Staff/PGR projects: applications must be submitted to the Research Office at least one month prior to the date of a Research Committee meeting in order to be appraised by the School Ethics Officer and considered for approval at that meeting. Applications and recommendations will be circulated to Committee members in advance of the meeting. Dates of Research Committee meetings can be found in the School calendar of meetings.

UG/PGT projects: applications can be submitted to the School Ethics Officer at any time.

Appeals

If you are dissatisfied with the decision made by the School Research Committee you should in the first instance discuss this with the School Ethics Officer. If discussion is unable to resolve the issue satisfactorily an appeal against the decision of the School Research Committee may be made to the University Research Ethics Committee via the School Research Committee and the Head of School. However, it should be noted that the University Research Ethics Committee will not normally interfere with a School Research Committee decision to require revisions to the project, such as to amend an information sheet or consent form. The University Research Ethics Committee is concerned only with the general principles of natural justice, reasonableness and fairness of the decision made by the School Research Committee.

Consideration of the application by the University Research Ethics Committee

The University Research Ethics Committee will provide general advice to the School Research Committee and will refer the matter back to them with that advice for them to make a decision. In such cases, to avoid additional delay to the applicant, the School Research Committee may consider the application between meetings if necessary.

Monitoring of projects requiring ethical approval

Projects that require ethical approval will be monitored on an annual basis by the School Ethics Officer to ensure that agreed standards are being met. Researchers will be required to report on projects and provide evidence of the research methods adopted as appropriate.

Contacts

Who to contact in the School:

To submit applications (staff and PGR students): Sheila Stockman, Secretary to the Research Committee - Research Office, ext. 74930, Stockman@cardiff.ac.uk

To submit copies of UG/PGT projects approved by the SEO: Sheila Stockman, Secretary to the Research Committee - Research Office, ext. 74930, Stockman@cardiff.ac.uk

To seek further information/advice: Fiona Pac-Soo, Research Administrator, ext. 77336, Pac-SooF@cardiff.ac.uk or School Ethics Officer, Prof Peter Wells, WellsPN@cardiff.ac.uk, ext. 74154.

APPENDIX A

CARDIFF SCHOOL OF ENGINEERING

PROCEDURES FOR ETHICAL APPROVAL OF RESEARCH

Staff

1) Complete the ethical review pro-forma, available from the Research Office.

(This can be done at the stage of applying for funding. PIs will be asked to indicate in research grant checklists whether or not a project involves human participants, materials or data, and will be sent ethical approval pro-formas as appropriate.)

2) Submit the pro-forma and any supporting documents to Sheila Stockman, Secretary to the ENGIN Research Committee, at least one month prior to the next meeting of the committee, for consideration at that meeting.

(Meetings of the Committee are published in the School's Calendar of Meetings at the start of each session).

3) The School Ethics Officer will consider applications and make recommendations on approval to the Committee (in time for paperwork to be circulated to Research Committee members one week prior to the meeting)

4) The Research Committee will review the application and recommendations from the School Ethics Officer at the meeting.

5) Following the meeting, applicants will either receive approval from the Chair or recommendations for revision of the proposal.

6) Projects approved by the Committee may commence immediately.

7) Where proposals require revision, applicants will be given written guidance on the alterations recommended by the Committee. Revised proposals should then be submitted to the Committee Secretary for approval at the next meeting.

Research Students

Research students should follow the procedure outlined for staff applications, but should, in addition, obtain the signature of their supervisor on the form, prior to submitting the application to the Committee Secretary.

Ethical review application forms will be available from the Research Office. Applications should be made ahead of the start of any project.

Undergraduate and Postgraduate Taught Students

UG and PGT students should also complete the pro-forma and submit this to their project supervisor, who will seek approval from the School Ethics Officer, via the Research Office. A copy of the approved application should be submitted to the Secretary of the ENGIN Research Committee. Approved UG and PGT projects will be reported to the Committee.

Guidance on completing the ethical approval pro-forma (available from the Research Office) can be found in Appendix B.

APPENDIX B

CARDIFF SCHOOL OF ENGINEERING

GUIDLELINES ON PREPARING AN ETHICAL APPROVAL APPLICATION

Introduction

The University requires all Schools to have in place procedures for the ethical approval of non-clinical research project involving human participants, human material or human data. In ENGIN, the School has established procedures for applying for ethical approval of research projects (see Appendix A) and has appointed a School Ethics Officer who will report to the Research Committee.

What happens if I want to publish the research?

There are ethical issues involved in respect of publishing research.

You must tell the proposed research participant in advance if you have any intention of publishing the results of the project. You must also explain the extent to which, if at all, any identifying information about the research participant will appear in the publication. If identifying information about the research participant is intended to be published, you must obtain and keep specific written agreement to this from the research participant. Preferably these issues should be addressed in the information sheet and consent form that are given out before the research starts. This will prevent any disappointment if the individual, when asked later, chooses not to agree and therefore reduces the value of the information that can be published.

In most cases you will not be the only person with an interest in publishing the results. Research is a collaborative activity and, in the case of student work, supervisors may expect to claim some contribution.

Informing Research Participants of the Results of Research

You are encouraged to consider the issue of informing research participants of the results of the research or where they may be able to get access to this information, although research participants may not be able to be given their individual results. Taking part in non-clinical research is a voluntary matter requiring good-will on the part of the community and it is appropriate for research participants to be able to receive feedback on research they have been involved in where this is possible.

Human Materials

The use of human materials in research is governed by the Human Tissues Act. It is the responsibility of researchers to ensure that they comply with the requirements of the Act.

Human Data

Confidentiality, privacy and data protection are the key issues here. Links to sources of guidance such as the Data Protection Act can be found in the Research Ethics pages of the Cardiff University website – see below for link.

Confidentiality

The University is committed to rigorous and objective inquiry and supports academics in pursuing their research in an environment that affirms academic freedom. The University also acknowledges the importance of confidentiality as a guiding principle in research involving people, human material and human data.

Duty of Confidentiality

A duty of confidentiality will exist between researchers and participants such that confidential information revealed by a participant to a researcher can only be disclosed to others if the party providing the information has given specific authorisation or the researcher is under a legal obligation to disclose it. In some cases researchers may be under a professional obligation to disclose information to third parties. Whether information is confidential will depend on the circumstances but the key factor is whether or not the provider of the information would have considered it as confidential and would expect it to be treated as such. If the answer to both questions is "yes", then the duty of confidentiality will arise. The duty also arises when the researcher has volunteered to keep confidential the information and/or the identity of the provider.

As a result of this duty there is a need for researchers to be aware of any circumstances, such as professional codes of practice, that preclude them from being able to give absolute assurances of confidentiality.

Obligations on Researchers:

In the light of the above paragraph, it is important that researchers:

(a) do not convey personally identifiable information obtained in the course of research work to others, except with the express permission of the research participant unless either alternative arrangements have been agreed by a research participant (see (b) below) or where the researcher is subject to a legal obligation to disclose that information;

(b) do not give unrealistic guarantees of confidentiality and anonymity and be aware that legal challenge may prevent you from honouring such a guarantee. In some circumstances it may be necessary to inform research participants of obligations under law, such as the possibility that the researcher will be required to give evidence or reveal documents, which may make it impossible for certain information to be kept confidential without breaking the law. In other cases, it may be that the researcher's professional obligations would require the disclosure of information, for example, where the welfare of a child is concerned. The research participant needs to be made aware of the possibility of future disclosure in order to be able to decide whether to take part in the research. If the researcher has made it clear that information may be passed on as a result of legal or professional obligations and the participant nevertheless agrees to take part, the researcher may pass on that information even if the participant subsequently objects. However, passing on confidential information without the express permission of the participant is not to be undertaken lightly and legal and professional advice must be sought immediately if this is contemplated;

(c) where possible, anticipate threats to the confidentiality and anonymity of research data. The identities and research records of those participating in research should be kept confidential whether or not an explicit pledge of confidentiality has been given. Researchers should also consider whether it is either necessary or appropriate to record certain kinds of sensitive information;

(d) take appropriate measures to store research data in a secure manner. Researchers should have regard to their obligations under the Data Protection Act 1998 and ensure that appropriate methods for preserving the privacy of data are used while also allowing participant access to information where this is requested by a participant;

(e) take care to prevent data being published or released in a form which would permit the actual or potential identification of research participants. In circumstances where it is difficult to protect the anonymity of informants and research participants, they must be informed of this fact before they are asked to take part or, if the possibility of publication had not arisen at that time, they must be re-contacted and their agreement obtained;

(f) ensure that the designated Ethics Officer is informed of any research proposal that might raise questions about guaranteeing participant confidentiality. If there are significant queries about this matter they should be brought to the University Research Ethics Committee for consideration and guidance;

(g) ensure that data collected is used only for legitimate academic purposes;

(h) are aware of the need to limit the University's potential liability in the event of a breach of confidentiality.

Further guidance

Further information and guidance on ethical considerations in research involving human participants, human data and human materials is available on the Cardiff University website at:
http://www.cardiff.ac.uk/schoolsanddivisions/divisions/racdv/resgovethics/ethics/issues.html

Codes of conduct for ethical research are also published by some professional bodies. See http://www.cardiff.ac.uk/schoolsanddivisions/divisions/racdv/resgovethics/ethics/professional.html for links to relevant codes in the field of science and engineering.